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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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THE LIMITS OF THE UNIVERSE

BY W. H. S. MONCK

THE question whether the Universe is limited or unlimited is a very wide one and, as often happens with wide questions, one to which it is not easy to find a satisfactory answer. It is a question, however, that is forcing itself more and more on our attention, and it is therefore worth while to consider what knowledge we possess on the subject, as well as the larger possibilities about which we know nothing at present.

With regard to all bodies, except the earth and the meteorites which fall upon it, our only source of knowledge is the effects which they produce on us; and the effects which carry us farthest, light and photographic influences, as well as heat and electricity, undoubtedly depend upon the medium, known as ether, which occupies the space between us and them. That gravitation depends on this ether has not yet been proved, but gravitation alone would carry us a very short distance towards detecting the existence and properties of bodies other than the earth. For all practical purposes, therefore, I think I may lay down that the presence of ether is a necessary condition for our knowledge of

the existence of heavenly bodies; and if this ether has limits, the Universe as known to us is confined within the same limits. Bodies may exist beyond these limits and possibly exercise an attraction or some other influence upon us, by which at some future date we may succeed in proving their existence, but I see no prospect of this at present. But has the ether a limit? The small number of shining bodies visible in any region of the sky does not prove this. We know that, wherever we can ascertain the facts, the space occupied by matter is very small compared with that which seems to be occupied by ether only: and there is no reason why it should not be smaller in some directions or at some distances from us than elsewhere. I fail to see any reason for believing that the ether is finite. Its particles appear to be self-repulsive and would therefore tend to overpass any temporary limit. But is space infinite or does it return into itself as some of the advocates of the non-euclidean geometry seem to maintain? I am afraid I cannot answer this question. Most men I think, however, have a natural belief in the infinity of space and I do not see any reason for discrediting this natural belief. But if space be finite, the Universe must, of course, be finite; and if the ether be finite, our present knowledge is limited to the region occupied by the ether. If the ether be infinite, the Universe is in one sense infinite; for ether is a real thing that undulates and conveys the various forms of force from one place to another; and I do not think that we can doubt that it occupies space, although it may not resist the entrance of bodies into the space which it occupies, and it certainly does not gravitate. We must not confound reality with matter. This ether is real and contributes as much to our knowledge as matter does. Whether it possesses any original action of its own may be doubted, or merely transmits force from one material body to another. But we must not identify gravitation or resistance with reality and assume that where there is no ponderable matter there is nothing. It seems indeed a strange hypothesis that ponderable bodies are constantly producing vibrations in the ether which pass away to infinity and never come back to us in any form. An enormous

sphere of ether, with the waves reflected back from the surface and ultimately re-heating the bodies that had been cooled in emitting them, is a much more manageable hypothesis as well as more consistent with the very high temperature of a great number of stars round us and with the proofs afforded by geology that the solar heat has not materially varied during a vast number of years. That every material body in the Universe is losing heat—losing force—is a startling conclusion to arrive at, especially to those that hold that force is indestructible. But possibly the ether when once set in motion continues to vibrate independently without any additional expenditure of force except in those directions in which the waves are absorbed by a material body. We know too little on these subjects at present to dogmatize. For my own part I have a stronger belief that the quantity of force in the Universe is constant than that the quantity of matter is so. Indeed matter—at least outside of the earth—is only known to us as force. Attraction is force and if we deprive matter of its attraction, what becomes of it? But that attraction may be diminished by converting part of it into some other form of force seems to me more probable than that the total amount of force in the Universe should be diminished.

With these prefatory remarks I come to deal with material bodies in space. Now the first remark that here occurs to me is that these bodies have a very wide range in respect of mass, and that even if self-luminous very small bodies at a considerable distance from us could not be either seen or photographed by any instruments which we at present possess. Meteors numbering thousands of millions pass within a moderate distance of us, and yet we should probably never have known of their existence if some of them had not entered our atmosphere. All attempts hitherto made to photograph them in the open sky have failed. Some of those which have entered our atmosphere are supposed to have weighed only a few ounces; and most probably still smaller ones have entered it but produced too little light to be detected. It is quite possible that meteors are constantly entering our atmosphere which do not weigh more than a grain.

Little more than a century has elapsed since the asteroids, as we now call them, were entirely unknown. Over 500 are now known to us and more are being discovered every year. With the exception of Eros they all circulate in the region between Mars and Jupiter. But when we consider how rapidly the light of an asteroid diminishes with the distance, can it be affirmed that if the asteroids were equally numerous beyond the orbit of Jupiter we would have detected some of them? At all events if we travel farther out, those whose orbits are nearly as distant as that of Saturn would be quite incapable of detection, while the rings of Saturn are suggestive of minute captured asteroids or meteors. On the other hand no doubt there are bodies in space very much larger—perhaps 10,000 times larger—than the Sun. But the small bodies seem to be much more numerous than the large ones; and it may well be that each fixed star has its own collection of small dark bodies revolving round it as the Sun has. It is evident that the farther these small bodies are situated from us the less chance we have of seeing them or otherwise detecting their presence. It may be said that they would contribute to the general illumination of the sky, with which I shall deal hereafter, but it is clear that individually it would be impossible to detect them, and our failure to detect stars in any particular direction does not disprove the existence in that direction of a considerable number of bodies too small to be individually perceptible and not close enough to present a continuous luminous surface like the rings of Saturn. And with these very small bodies I may class gases of great tenuity. There are numbers of nebulæ of great extent whose light is so faint that it requires a skilled observer with a very powerful telescope to detect them. New nebulæ are being detected every year and there are vast numbers still undetected. Although occupying perhaps a large amount of space and within what may be termed a measurable distance of us their mass is too small and their light too faint to be detected by ordinary methods.

But it is not merely owing to the small mass of remote bodies that they escape detection. The defect in luminosity, which

affects photographs as much as telescopic observations, is equally potent. The difference between a self-luminous body and one which shines merely by reflected light is sufficiently obvious. The Moon presents to us as large a disc as the Sun. If self-luminous in the same degree it would be equally bright. And we have now reached a stage at which I think we can affirm that even self-luminous bodies possess that quality in very different degrees. There are stars whose luminosity much exceeds that of the Sun. There are others whose luminosity sinks far below it. The spectra of the stars indeed afford us a kind of measure of their relative luminosity. But there are undoubtedly stars whose luminosity is so small that without the aid of the spectroscope we should never have detected their existence. Such, for instance, is the dark star that eclipses Algol periodically in a little less than three days. It may not be altogether dark, for the light of the principal star is never totally eclipsed—a remark which applies to all variable stars of the same type as Algol—but supposing that the bright Algol were suddenly annihilated it may be doubted whether any existing telescope would detect the eclipsing satellite. The eclipse in this case would suggest a dark star even independently of the spectroscope, but there are other instances —*α Virginis* for example—in which there is no eclipse, yet the motions of the bright star in the line of sight, as revealed by the spectroscope, clearly show that it is being influenced by a dark companion of considerable magnitude. Sirius contributes its evidence on this subject. Its satellite probably presents towards us a disc at least half as large as that of the bright star but its light is 10,000 times less. If removed to 10 times its present distance Sirius would still be easily visible to the naked eye, while the satellite, whose mass is comparable to that of the great star, would no doubt have remained undetected. The fact that the motion of Sirius was being affected by a satellite was in fact known for some time before the satellite was detected. Remarks of this kind have a two-fold bearing. If, whenever we use a higher telescopic power or take a photograph with longer exposure, we discover a number of additional stars it does not

follow that we have thereby penetrated farther into space. Our discoveries may consist of smaller or less luminous bodies within the same spacial limits as those detected by less powerful instruments. It may be that we see at present as far as the limits of the Universe, and that what remains to be done may be to discover new objects nearer home. On the other hand we must bear in mind that small or slightly luminous bodies if placed at a great distance must necessarily escape our observation, and that apart from considerations as to the general illumination of the sky the failure to detect them affords no evidence whatever of their non-existence. This aggregate light of the sky is therefore the main thing that we have to look to for guidance. And if the consideration of this aggregate light leads us to conclude that there is a gradual thinning-out of the stars as we move outwards from the earth taken as a centre, we must recollect that the same appearances would result from the stars on the average becoming smaller or less luminous instead of fewer as we made this outward expedition. I doubt if we shall ever be in a position to prove that dark bodies in space do not extend to infinity, though analogy may lead us to some more or less probable inferences on that subject.

With respect to the total light of the sky, let us begin by supposing that the distribution of the stars is (on the average) uniform at all distances from us as regards number, mass and luminosity. Take Pogson's scale of magnitudes. Draw a number of spheres with the earth as centre, each radius being 1·585 times the preceding one. The stars in each inter-spheral space will, on the average, be each 1·585 times as far away from us as those in the preceding one, and will therefore be on the average fainter by one magnitude, since $(1{\cdot}585)^2 = 2{\cdot}5112$. (I suppose the medium to be perfectly transparent). But what will their number be? The total number of stars in any sphere will be $(1{\cdot}585)^3$ that in the preceding sphere—in round numbers 4 times. The interspace will therefore contain three times as many stars as the preceding sphere and, as we can easily see, four times as many as the preceding interspace. The result is that the total

light of the stars of the $n+1^{th}$ magnitude will be $\frac{1}{0\cdot632}$ or 1·585 times as great as that of the stars of the n^{th} magnitude ; and as the light of the stars between magnitudes 2 and 3 is a very perceptible quantity, if this increase of light went on at every subsequent magnitude the total light would ultimately become infinite. There are, of course, obvious qualifications to this latter conclusion. Stars for example would get in each other's way. If the Sun be regarded as a star of average brightness, the total light of the sky could never exceed that of an uniform covering of suns, some a little brighter than the actual one and others a little less so. But let us take a great stride downwards and reduce the brightness of the sky on the average to $\frac{1}{100000}$ part of that of the Sun. This is the highest computation for the brightness of the illuminated part of the Moon. But the contrast between the illuminated portion of the Moon and the surrounding sky need not be insisted on. Objects much more feebly illuminated than the Moon similarly shine out in contrast to the surrounding sky. The reflected light which reaches us from Neptune is much fainter than that of the Moon—probably 100 times fainter—yet Neptune stands out as a star not as a dark spot in the sky. And let me remark that the reasoning here applied to the entire sky is equally applicable to any section of a cone having the earth for its vertex and terminated by one of the spheres which I have been considering. But can it be said that any part of the sky—except perhaps the very small patch occupied by a dense cluster—presents to us a brightness even approaching to that of the illuminated part of the Moon? The total light of the sky is not merely less than we should expect on the hypothesis of bright stars uniformly distributed extending to infinity and shining through a perfectly transparent medium, but it is almost incalculably less. It makes no approach whatever to the state of things required by that hypothesis. Nor is the force of this reasoning much weakened if, for instance, we confine ourselves to the Galaxy and neglect the rest of the sky. The brightness of the Galaxy even at its richest part will not compare with that of the disc of Neptune. Indeed for a few days after

new moon the earth-shine on the illuminated part of the Moon is more powerful than the sky-light and that part of the Moon becomes visible as a bright and not as a dark object. There is here a double reflection of the sun-light, and the proportion of that light which reaches us after being reflected from us to the Moon and back again from the Moon to us must be exceedingly small. Nor, I think, will it be denied that the Moon (even when not full) bursting through a small rift in a densely clouded sky sometimes gives us more light than we receive from the entire sky on a clear moonless night. The light of an average portion of the sky equal in angular measure to the Sun's disc is probably smaller in the proportion of at least a million millions to one. Uniform distribution of luminous stars extending to infinity in a transparent medium is completely excluded by this state of facts, but that supposition is by no means necessary for an infinite Universe.

Dealing only with luminous bodies and assuming the medium to be transparent, the thinning-out of the stars (on a general average) sets in very early. The theoretical ratio of four-fold multiplication in number for each descent of one magnitude is never realized. I tried this some years ago with the *Harvard Photometry* and found it to be so, and Mr. Gavin Burns has lately tried it with a much larger number of stars, whose light has been photometrically measured with the same result. But though the increase is not four-fold, I found it to be roughly speaking about three-fold, and Mr. Burns has carried this latter proportion two magnitudes lower down than I did. But each star of a given magnitude gives 2·512 times as much light as a star whose magnitude is next below it, and if the latter stars are three times as numerous as the former the total light of the stars of the $n+1^{\text{th}}$ magnitude will exceed the total light of the stars of the n^{th} magnitude in the ratio of about six to five. If the thinning-out never became more rapid than this it is plain, on the grounds already indicated, that the whole sky should glow with a brightness exceeding that of the illuminated portion of the Moon. The results which hold good up to stars of the seventh or eighth

magnitude can, I think, hardly continue to hold good up to the twentieth. The proportion of stars of the $n+1^{th}$ magnitude to stars of the n^{th} magnitude must at a comparatively early stage drop below 2½ to 1 and, I think, very considerably below it. The total light of the stars of the one-thousandth magnitude must, I apprehend, be greatly less than that of the stars of the tenth magnitude or else the total light of the sky would be vastly greater than it is. Much further observation with powerful instruments, however, will be necessary in order to trace the rate of this thinning-out and the laws which regulate it.

The most obvious explanation of this thinning-out of the stars is that the Sun is one of a cluster and that its position in the cluster is pretty nearly a central one. The great distance which separates the Sun from its nearest neighbors among the stars renders this hypothesis a startling one; yet, great as these distances are, they may be insignificant compared with those which separate bright stars in other regions of the sky. The cluster theory, moreover, receives some confirmation from the fact that the Galaxy—the greatest star system known to us—appears as nearly a great circle in our sky—as a ring in the centre of which we are situated. Do all or almost all the visible stars belong to this system, which may be roughly compared (on that assumption) to a block-wheel in which we are imbedded but which we could get out of much sooner in the direction of its thickness than in that of the rim? As far as the stars are concerned a good deal might be said in favor of this view, but the nebulæ do not fit conveniently into our block-wheel assumption. As another hypothesis we may suppose that we are situated in a portion of the Universe where bright stars are unusually numerous and dark celestial bodies unusually few. If it be true that the Sun and all the bright stars with which we are acquainted are constantly losing heat by radiation and cooling down in consequence, some such theory as this seems requisite; for unless the ether itself absorbs heat, what one body loses others must gain. There is no loss but merely an interchange (accompanied perhaps by change of form). This hypothesis may reconcile the com-

paratively small amount of sky-light with the assumption of an infinite Universe, but the evidence in its favor must be very slender for a long time to come.

Finally I may suggest a theory which seems to be more capable of confirmation or refutation by observation than the others, viz., that light is absorbed by the medium in a proportion which increases with the distance and practically extinguishes the light of stars whose distance is sufficiently great. The ether itself, as has been suggested, may absorb a certain quantity of light; but it is not necessary to assume this. The imperfect transparency of the medium may arise from the presence of dark bodies in it, or bodies which, though not quite dark, intercept the light of brighter bodies. We come in contact with many millions of visible meteors every year, and besides these there are probably as many millions of others which enter the atmosphere in such fine dust that we never see them or at most merely notice a faint glow if they are very numerous. Every year, moreover, we are discovering new nebulæ, many of which occupy large portions of space while giving very little light. These may suggest to us dark nebulæ which must remain unknown until perhaps rendered visible by a star rushing into them or some other great disturbance. Now if meteors and nebulæ are to be found at all distances and in all directions from us, they must intercept a good deal of light and they will intercept a larger proportion of the light as the distance of the star increases until at last almost the whole light of the star would be excluded owing to the want of complete transparency and the enormous thickness of the medium which the light must traverse in order to reach us. And even supposing the distribution of the stars to be, roughly speaking, uniform and the universe of stars to be infinite, it is plain that this want of complete transparency in the medium would cause an apparent thinning-out of the stars and give an appearance of finiteness to the Universe. This hypothesis, as I hinted, is more capable of being tested by experience than the others. The Sun not being a very prominent star, it is natural to conclude that the motions of stars are unaffected by

their distance from the Sun and are on an average the same at all distances from us when we are dealing with a large number. The natural conclusion, however, may be tested as follows. We can ascertain the velocity of stars in the line of sight by means of the spectroscope, and on comparing a large number of these measurements we can judge whether the velocities of stars increase or diminish with their distance from the Sun or give the same average velocity for all distances; for it is not likely that the total motion would follow a different law from the radial motion thus observed if we collected a sufficient number of observations. Now with a transparent medium we may expect the average distances of the stars of the $n+1^{th}$ and the n^{th} magnitudes to be in the ratio of 1·585 to 1, in which case the proper motion of the more distant stars would (if the actual velocity were equal) be reduced in the same proportion. But with an imperfectly transparent medium the more distant stars would lose a larger proportion of their light than the nearer ones, and the ratio of the distances instead of being 1·585 to 1 would be less, and with faint stars probably much less. And, of course, the proper motions as measured on the sphere would be reduced in proportion to the real distance, not the theoretical one, and would consequently be larger in the case of the more distant stars than if computed on the assumption that the distance had been increased in the ratio of 1·585 to 1. In short the fainter stars would appear to be moving faster than the brighter ones (when we made the correction for their theoretical distance) for the simple reason that their theoretical distance would be too great. The average proper motions for stars with different spectra are so different that I think they ought to be tried separately. But even without using this precaution some recent inquirers have arrived at the conclusion that the fainter stars *are* moving faster than the brighter ones. Their computations were no doubt based on the assumption of a transparent medium; but it seems simpler to suppose that the medium is not transparent than that the average velocity of star-motion becomes greater the farther we proceed outwards from the Sun.

Binary stars will, I think, afford another test. Here we may hope to ascertain the parallax (or distance) by means of the radial velocity and the elements of the orbit; and we would in that event know also the mass and the kind of spectrum. Then the question would arise, Is the light of the more distant binaries fainter than we should expect from the mass, the distance and the spectrum? In individual cases it might be difficult to obtain a satisfactory answer, but the average of a number of binaries should enable us to do so. Determinations of parallax only would also assist us. If it proved that stars with small parallaxes were, after allowing for the difference of distance, fainter than those with larger parallaxes, an absorbing medium would be strongly suggested—more especially if the result appeared to hold good for stars with each type of spectrum taken separately. I may note, however, that with regard to very distant stars, whose proper motion is very small, errors of observation will tend to exaggerate the real proper motion when we are merely considering the quantities irrespective of the sign. The + and − errors may nearly cancel each other on a general average, but where the real motion is almost *nil* the table will probably make it larger than it really is, whether with the right sign or the wrong one. This fact, besides providing imaginary evidence for my hypothesis, may, I think, have misled inquirers on other points. It would evidently render the effect of the Sun's motion in space less perceptible in the case of the more distant stars; while if (as I believe to be the fact) the errors in Declination were less than those in Right Ascension it would make the effect of the Sun's motion in space more sensible as regards Declination than as regards Right Ascension, with the result of assigning too northerly a position for the point towards which the solar system is moving. In the great majority of stars with small proper motion the true proper motion is even smaller than we suppose it to be.

An objection to this hypothesis may be urged on the ground that if space contained a sufficient amount of matter to intercept a good deal of light, it would offer a resistance to bodies moving

in it, the effects of which must in the course of time become perceptible. That may be, if sufficient time were given; but the resistance would, I fancy, be very small. However, it is also possible that the effects of the resistance may be counteracted by another agency. What if, instead of the instantaneous action of gravity on the one hand and motion through an absolutely resisting medium on the other, we are really dealing with gravity transmitted with great velocity and a medium which offers a very slight resistance to a moving body? Taking a body like the earth, I believe the effect of a propagation of gravity in time would be to enlarge the orbit and make the earth revolve round the Sun at a constantly-increasing distance, while the effect of a resisting medium would be to contract the orbit and make the earth approach nearer to the Sun on each successive revolution. If so, where is the improbability that, after a certain number of years, a position of equilibrium would be reached and the earth would continue to revolve steadily in the same orbit until it moved into a region of space where the resistance was a little greater or a little less than before?

Two or more causes, however, may be joined in explaining the small amount of light which reaches us from the stars, and I am inclined to think that the Sun is a member of a cluster, though not a very dense one, and also that the medium through which we look at distant stars is not wholly transparent. In any event I think we have as yet no proof that the Universe is finite—still less that it is infinite; and that we have a good deal more to learn before we can pronounce either conclusion to be so much as probable.

ERRATA IN FORMER PAPERS.

Volume II., p. 227, l. 4, *for* R. A. 200° *read* R. A. 300°.
" " 229, last line of note, *for* by *read* viz.
" " 300, l. 8, *for* of *read* by.
" " 300, l. 16, *for* by *read* for.

THE DESIGN OF SPECTROGRAPHS FOR RADIAL VELOCITY DETERMINATIONS*

By J. S. Plaskett

THE subject of spectroscopy is so broad that one can not hope in a single paper to do more than touch upon a single aspect of it, and even then one must further limit his treatment to a particular application of this phase. Consequently I propose to present some considerations bearing upon the design of spectrographs suitable for the accurate determination of stellar radial velocities. This branch of spectroscopy is comparatively new and is still probably only in the experimental and tentative stage. The present practice in this line has, however, reached a certain uniformity, and the general theoretical principles governing the design of spectroscopes may be applied to the case under consideration, modified, of course, in many ways by the experience of the various observers. The question is one of a judicious combination of theory and experience, and I propose to present my own views, founded, of course, on theoretical considerations, but modified partly by the practice of other spectroscopists, partly by my own experience in the work, and by the results of special investigations bearing on the most suitable form and dimensions of the instrument.

The determination of the radial velocities of stars by means of the spectroscope is one of the most exacting of astronomical investigations and requires the closest attention to all details to insure accurate values. This will be more readily recognized when the smallness of the displacement of the spectral lines on which the velocity depends is known. Thus in the Ottawa spectrograph a velocity of 20 km. per second, which is greater than the average velocity of the stars, causes a displace-

* Read before the R.A.S.C, Ottawa, May 28, 1908.

ment at H_γ, the centre of the measurable range, of about $\frac{1}{2700}$-inch for the single-prism, and about $\frac{1}{900}$-inch for the three-prism form of the instrument. The accidental errors arising in the measurement of this displacement, in spectra with good lines, are, however, not so much to be feared as systematic displacements of the lines as a whole, of which no evidence is given in the measurements, caused by flexure of the parts of the spectrograph, by temperature changes in the prisms and lenses and also in the metal frame, by faulty adjustment of the focal positions of camera and collimator as well as by numerous other causes. Some idea of the magnitudes of these displacements may be gained from the following figures. An hour's exposure in one of the modern spectrographs introduces flexure displacement equivalent, in some positions of the telescope, to a velocity of 10 km. per second. A change of temperature of 1° C. in the prism displaces the lines by about 20 km., which may be increased further by the expansion of the metal parts. An inaccuracy in the focal setting of the camera of only 0·1 mm., $\frac{1}{250}$-inch, may, when combined with poor guiding, cause a displacement of about 5 km. It does not follow that such displacements necessarily cause a corresponding error in the velocity as they may be compensated for, partially at any rate, by a similar displacement of the comparison lines. But the possibility remains, and inaccurate results can only be prevented by constant and careful attention to all details. It becomes, therefore, a question of equally great importance with proportioning the optical parts to give accurately measurable spectra in the shortest possible exposure time, to so design the whole instrument that systematic errors due to the above or other causes may be provided for and eliminated as far as possible.

The design of a spectrograph may be most conveniently attacked under two separate headings.

1. The character and proportions of the optical parts.

2. The mechanical connection of these parts into a symmetrical and stable whole, with suitable auxiliary devices for controlling the temperature, applying comparison, etc.

The Optical Parts

Up to the present, prisms of dense flint glass have been the sole dispersing medium used for radial velocity work. Gratings, so useful in other branches of spectroscopy, have not yet been applied in this work, chiefly on account of the division of the incident pencil into a number of spectra with the consequent loss of light, and also on account of the difficulty of maintaining their position invariable without distorting the surface. Prisms have very decided advantages over gratings in this respect as, when set at minimum deviation, a small angular rotation of the prism will scarcely displace the spectrum lines, while with a grating the angular displacement of the lines is double that of the prism. The optical parts of a spectrograph are then,—1. The slit, whose width is usually between 0·025 and 0·051 mm., one and two thousandths of an inch, on which the star image is condensed by the telescope. 2. The collimating lens placed at its focal distance from the slit and consequently rendering the incident pencil parallel. 3. The prism or prisms placed at minimum deviation for some particular wave-length usually near λ 4415. 4. The camera lens which forms an image of the spectrum on the photographic plate.

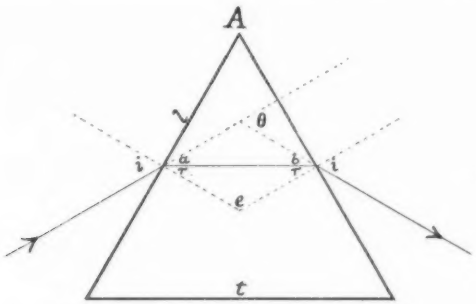
As the terms dispersion, resolving power, purity, etc. will be frequently used, and as the prism angle, thickness of base, etc. require computing, it seems preferable to give here a short synopsis of the theory involved and the formulæ used, particularly as these are not readily available in a suitable form or collected together in one place.

When a pencil of parallel white light is incident upon a prism, the direction is changed, the light is deviated, and it is also decomposed into its constituent colors forming a spectrum, the wave-lengths of the light giving rise to these color-sensations diminishing as you go from red to violet. The fundamental formula determining the direction after refraction is, i being the angle of incidence, r of refraction,

$$\sin i = \mu \sin r.$$

μ is the index of refraction which varies for different materials

and for different wave-lengths in the same material, increasing as the wave-length diminishes. In all spectroscopes the prisms are used at the position of minimum deviation, which, it may be easily shown, requires the angles of incidence and emergence to be equal. The discussion will therefore be confined to this particular case, resulting in a considerable simplification.



$$A + e = 180°$$
$$e + 2r = 180°$$
$$\therefore r = \frac{A}{2};$$
$$\theta = a + b;\ a = b,$$
$$\therefore a = \frac{\theta}{2}.$$

$$i = a + r = \frac{A + \theta}{2}, \text{ and as } \sin i = \mu \sin r,$$

$$\mu = \frac{\sin \frac{A + \theta}{2}}{\sin \frac{A}{2}}.$$

If a is aperture of incident pencil just filling prism

$$l = a \sec i$$

$$t = 2l \sin \frac{A}{2} = 2a \sec i \sin \frac{A}{2}.$$

If θ the deviation and μ the index are given to find A or the angle of the prism,

$$\sin \frac{A + \theta}{2} = \mu \sin \frac{A}{2} \text{ and reducing and simplifying}$$

$$A = 2 \sin^{-1} \frac{\sin \frac{\theta}{2}}{\sqrt{\sin^2 \frac{\theta}{2} + \left(\mu - \cos \frac{\theta}{2}\right)^2}}.$$

The dispersion of a prism is usually defined as the ratio of the change in deviation to the change in wave-length or $\frac{d\theta}{d\lambda}$. As the deviation varies with the index of refraction, and as the latter varies with the wave-length we may put

$$\frac{d\theta}{d\lambda} = \frac{d\theta}{d\mu} \cdot \frac{d\mu}{d\lambda}, \text{ but}$$

$$\mu = \frac{\sin \frac{A + \theta}{2}}{\sin \frac{A}{2}}$$

$$\therefore \frac{d\theta}{d\mu} = \frac{2 \sin \frac{A}{2}}{\cos \frac{A + \theta}{2}} = \frac{2 \sin \frac{A}{2}}{\cos i}$$

$$= \frac{2 \sin \frac{A}{2}}{\sqrt{1 - \sin^2 i}} = \frac{2 \sin \frac{A}{2}}{\sqrt{1 - \mu^2 \sin^2 \frac{A}{2}}},$$

$$\text{also } \frac{d\theta}{d\mu} = \frac{2 \sin i}{\mu \cos i} = \frac{2}{\mu} \tan i.$$

To obtain $\frac{d\mu}{d\lambda}$ we require a relation between λ and μ. The simplest is obtained from Hartmann's interpolation formula

$$\mu = \mu_0 + \frac{c}{\lambda - \lambda_0}$$

$$\therefore \frac{d\mu}{d\lambda} = - \frac{c}{(\lambda - \lambda_0)^2} \text{ and}$$

$$\frac{d\theta}{d\lambda} = \frac{d\theta}{d\mu} \cdot \frac{d\mu}{d\lambda} = - \frac{c}{(\lambda - \lambda_0)^2} \cdot \frac{2 \sin \frac{A}{2}}{\sqrt{1 - \mu^2 \sin^2 \frac{A}{2}}}.$$

Let us now consider resolving power or the ability of the prism to separate lines close together in the spectrum. Lord Rayleigh has shown, in the case of the image of an infinitely narrow slit produced at the focus of a telescope lens, that the

linear distance of the first diffraction minimum from the principal maximum is given by the equation

$$\frac{a\xi}{m\lambda f} = 1,$$

where a is the aperture and f the focus of the lens and m is a constant, 1·0 for rectangular and 1·2 for circular apertures.

$$\frac{\xi}{f} = \frac{m\lambda}{a}.$$

$\frac{\xi}{f}$ is then the least angular distance at which two rays can be separated. Calling the angle $d\theta$ we have

$$d\theta = \frac{m\lambda}{a}.$$

For the case of a prism we have

$$a = l \cos i,\ t = 2l \sin \frac{A}{2}$$

$$\therefore \frac{t}{a} = \frac{2 \sin \frac{A}{2}}{\cos i} = \frac{d\theta}{d\mu}.$$

Combining we get the minimum condition of resolution

$$t = \frac{m\lambda}{d\mu}.$$

Again, omitting the constant m, we have

$$d\theta = \frac{td\mu}{a} = \frac{\lambda}{a},$$

and multiplying by $\frac{a}{d\lambda}$ we get $a\frac{d\theta}{d\lambda} = t\frac{d\mu}{d\lambda} = \frac{\lambda}{d\lambda}$ where $\frac{\lambda}{d\lambda}$ is the minimum value which permits resolution of close lines. $\frac{\lambda}{d\lambda}$ or the mean wave-length of a pair of lines which can just be resolved in a spectroscope, and the difference in wave-length between the two components is called the resolving power of the spectroscope and is usually designated by the letter R.

The linear dispersion $\frac{ds}{d\lambda}$ where f = focal length of camera is

$$\frac{ds}{d\lambda} = f \cdot \frac{d\theta}{d\lambda} = f \cdot \frac{R}{a}.$$

The resolving power R refers to infinitely narrow lines

through an infinitely narrow slit. When, as necessarily occurs in practice, neither of these two conditions holds, we speak of the purity of the spectrum or the practical resolving power for wide slits. Schuster has given a simple expression for the purity which is always a fraction of the theoretical resolving power R. This expression has been elaborated by Wadsworth, and later still, Schuster has given tables for determining the purity. But as no appreciable error will be introduced in the relative values used in this work it has seemed preferable to adhere to the simple form. If D = slit width and ϕ = angular aperture of the collimator = $\frac{a}{f}$, the Purity

$$P = \frac{\lambda}{D\phi + \lambda} \cdot R.$$

We have now obtained all the formulæ necessary to compute the data for any optical system and to compare the efficiency of different forms of spectroscopes. To take a concrete case, which is more applicable for our purpose than a general discussion, I propose to consider the question of the most suitable aperture to be given to a single-prism spectrograph which is being constructed for the Dominion Observatory. The present spectrograph, which is arranged to be used with either one or three prisms, has a collimator of 35 mm. aperture, 525 mm. focus, and two cameras, one for each form of 525 mm. focus. It performs excellently for both purposes, but when, as often happens, both single and three prisms are required on the same night the change from one form to the other is somewhat tedious, requiring 15 or 20 minutes, and, moreover, what is far more important, such change involves uncertainties as to the temperature conditions of the optical parts and therefore corresponding uncertainties as to the accuracy of the velocities obtained.

In order to fill the collimator lens completely with star light its aperture ratio $\frac{a}{f}$ must be the same as that of the equatorial. The aperture ratio of the Ottawa telescope is 1 to 15, consequently the focal length of the collimator must be 15 times the

aperture. This aperture is limited on the lower side by the condition that sufficient purity must be obtained, purity being proportional to the aperture, at a practicable width of slit, to so separate lines and blends of lines that sufficiently accurate identifications of lines and the true wave-lengths of blends may be obtained. It is limited on the upper side by the difficulty of obtaining homogeneous prisms of large size, by the increased absorption of such prisms, and by the increased size and weight of the instrument. In all the spectrographs used in radial velocity work the apertures lie between 30 and 51 mm., and these seem to be about the practical limits. It remains to determine the most suitable.

The basis of the discussion* rests upon the results obtained for the effective diameter of the star image given in my paper on the "The Star Image in Spectroscopic Work," No. II., which was read here last fall and published in the *Astrophysical Journal*, March, 1908. The results of a number of experiments, photographs of star images, spectra and trails, went to show that only rarely is the effective diameter of the image less than 2 secs. of arc (about 0·055 mm.) at the focus of the refractor. Generally the diameter of images and the widths of spectra and trails is considerably greater, increasing to over 0·1 mm. with longer exposures. As the theoretical diameter of the central disc is only 0·57″ (about 0·015 mm.) and as the condensing system of visual objective and photographic correcting lens is practically perfect the enlargement in diameter is undoubtedly due to atmospheric disturbances. These consist probably partly of a blurring or spreading-out of the central disc and partly of small displacements in all directions from its mean position. In consequence there results considerable loss of light at the slit jaws with the widths usually employed, and further experiments showed that the proportion transmitted varied almost directly with the width until this reached 3 or 4 secs. I reproduce below part of the table for slit transmission given in the paper referred to.

*An able discussion of this subject on somewhat similar lines, to which I am much indebted, has been given by Newall (*M. N.*, 65, p. 608).

SLIT TRANSMISSION

Slit Width		Comparative Exposure for Equal Intensity of Spectrum	
Linear mm.	Angular secs.	Observed	Corrected for Loss by Diffraction
0·025	0·91	100	100
0·051	1·82	40	50
0·076	2·73	27	35
0·102	3·64	25	32

This table shows that if the slit width can be increased the exposure is proportionately diminished, double the slit width halve the exposure, which means, of course, an increase in the output and in the practical range of the equipment. But on the other hand a widening of the slit, other conditions remaining unchanged, decreases the accuracy of measurement of the resulting spectra. This loss of accuracy is due to two causes: first, diminished purity rendering uncertain identifications and wave-lengths of blends, second, increased diffuseness of the spectral lines rendering measurements more difficult. We will take up these two considerations separately and find under what conditions the slit may be widened without loss of accuracy.

The equation for purity of spectrum, $P = \frac{\lambda}{D\psi + \lambda} R$, shows that the purity is almost proportionally diminished as the slit width is increased as $D\psi$ is, even for slit 0·025 mm., nearly ten times λ. To increase the purity of a spectrum only two courses are open—to diminish the slit width or increase the resolving power. As we wish to widen the slit the resolving power of the spectroscope must be increased, which may be done in three ways.

1. By increasing the aperture of the prism or prisms

$$R = \frac{\lambda}{d\lambda} = a\frac{d\theta}{d\lambda}$$

or R varies directly with the aperture.

2. By increasing the number of prisms.

3. By shifting the region of spectrum under observation towards the violet. The resolving power varies inversely as the cube or slightly higher power of the wave-length. This will be

seen directly when we compute resolving powers, but it follows at once by differentiating Cauchy's form of dispersion formula

$$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \ldots .$$

or simply

$$= A + \frac{B}{\lambda^2}$$

$$\frac{d\mu}{d\lambda} = -\frac{2B}{\lambda^3}.$$

The use of the second method increases the dispersion which is usually not allowable on account of the proportional increase of exposure time entailed. The third method can not be used with a refractor and glass prisms on account of the strong absorption of ultra-violet light by the glass of the lenses and prisms. With a reflector and a quartz or ultra-violet glass spectrograph it might be applicable. We are therefore practically limited to the use of a larger prism and consequently larger collimator and camera lenses.

The size of prisms in use in radial velocity work, as previously stated, lies between about 30 and 51 mm. Prisms of 51 mm. aperture are successfully used in the Yerkes spectrograph, but Frost's experience, as also that of Hale, in spectro-heliograph prisms, shows that the limit is nearly reached.

In discussing the necessary conditions for using a wider slit let us take as an example a comparison between the efficiencies of single-prism spectrographs of 35 mm., the aperture of the present instrument, and 51 mm. aperture, the latter having been decided upon, after careful consideration, as the aperture of the new instrument. A spectrograph of such aperture, outside of considerations of the homogeneity of larger prisms, is the practical limit, as regards size and weight, that can be attached to a 15-inch equatorial.

The glass generally used for the prisms is Jena Glass 0·102, Dense Silicate Flint, and this was chosen for the spectrographs here. It is very colorless, considering its density and dispersion. The indices of refraction of the particular melting from which

the present prisms were made, as furnished by the makers are as follows :

Wave Length	Index of Refraction
·00006563 cm.	1·6413
·00005893	1·6467
·00004862	1·6603.

From these values substituted in the Hartmann formula

$$\mu = \mu_0 + \frac{c}{\lambda - \lambda_0}$$

we obtain the values of the three constants μ_0, c, and λ_0,

$$\lambda_0 = \cdot00002190$$
$$\mu_0 = 1\cdot61146$$
$$\log c = \bar{6}\cdot115595.$$

From these constants were calculated for a number of wave-lengths, μ and $\frac{d\mu}{d\lambda}$. From $\frac{d\mu}{d\lambda}$, R was obtained for prisms of 35 and 51 mm. aperture, and of refracting angle 63° 50′, this being the angle required to deviate the ray at minimum, λ 4415, 60°. The formulæ used were previously derived and are

$$\frac{d\mu}{d\lambda} = -\frac{c}{(\lambda - \lambda_0)^2}$$

$$R = t\frac{d\mu}{d\lambda} \text{ where } t = 2a \sec \frac{A + \theta}{2} \sin \frac{A}{2}.$$

Wave-Length	μ	$\frac{d\mu}{d\lambda}$	R Prism 35 mm.	R Prism 51 mm.
4862	1·6604	1829	14420	21010
4550	1·6667	2343	18470	26910
4415	1·6701	2636	20780	30280
4341	1·6721	2822	22250	32420
4102	1·6786	3490	27520	40100
4000	1·6833	3983	31400	45750
3970	1·6848	4119	32380	47180

The resolving power for the two apertures obtained, the purity of spectrum for different slit widths is readily calculated from

$$P = \frac{\lambda}{D\psi + \lambda} R,$$

ϕ in this case being $^1/_{15}$ or ·0667. The results are given in the following table for the wave-length 4341 or H_γ, this being the usual central ray.

PURITY OF SPECTRUM

Slit Width	Prism 35 mm.	Prism 51 mm.
0·025	4596	6697
0·040	3114	4537
·051	2518	3670
·053	2084	3039
·076	1755	2558

These figures show that with the larger prism the slit may be made 50 per cent. wider and still have practically the same purity of spectrum, and consequently the same accuracy of velocity determinations.

The slit-transmission table previously given showed that an increase in slit width of 50 per cent, when below 0·076 mm., increased the quantity of star light transmitted by nearly 50 per cent.; consequently, other things being equal, half as many more spectra could be made in a given time. But an increase in the size of the prism means also an increase in the quantity of light absorbed by the glass of the prism, although the amount reflected will be the same. We can obtain an accurate knowledge of the quantity of light absorbed in the two prisms of 0·102 glass from Vogel's experiments (*Astrophysical Journal*, V., p. 75), who showed that H_γ light transmitted through 100 mm. of 0·102 glass suffered absorption of about 47 per cent. The absorption for prisms of 35 and 51 mm. aperture, average length of path 39 and 57 mm. respectively, may be readily calculated by the formula,

$$I_1 = I_0 K^{\frac{x}{a}},$$

where x is thickness of glass for which absorption is required, a is thickness for which percentage transmitted is K, I_0 intensity of incident, I_1 of transmitted beam. We obtain for prism of 35 mm. aperture 78 per cent., of 51 mm. aperture 71 per cent. transmission. If 100 be intensity of incident pencil for small prism then 150 will be intensity of pencil giving equal purity

with large prism. After transmission intensities will be 78 and 150 × ·71 or 106·5, respectively, and required exposures will be inversely proportional, or as 3 to 4, a very considerable gain. Even when the slight additional absorption in the thicker camera and collimator lenses is considered, a substantial saving of time will result by the use of the larger prism.

We have tacitly assumed in the foregoing discussion that a decrease of purity entails loss of accuracy in the velocity values. This is undoubtedly true for complex spectra such as those given by solar or allied type stars, spectra in which are hundreds of lines and in which every decrease in purity means increased uncertainty in the wave-lengths of the more complex blends of lines thereby produced. In the case of early-type stars, however, such as those of the hydrogen or helium groups, where there are only few lines, and these single, there can be no trouble with blends, and the question of the purity of the spectrum has not so much weight. On such grounds there would be no material advantage in using the larger aperture. However, a consideration of the second effect produced by widening the slit—the increased diffuseness of the spectral lines—will show a similar advantage for the larger aperture even where purity does not come into question.

This may be best shown, as before, by considering a special case and we may take the same example with advantage. The present single-prism spectrograph has a collimator objective of 35 mm. aperture and 35 × 15 or 525 mm. focus. The camera has a focus of 525 mm. and therefore the image of the slit on the plate will be of the same size, and the minimum width of line will be the width of the slit. The new spectrograph will have a collimator of 51 mm. aperture and 51 × 15 or 765 mm. focus. The camera will be of about 455 mm. focus. Hence the image of the slit on the plate will be diminished in the proportion of 455 to 765 or about $^3/_5$. If the camera were of the same focus as the one now in use, 525 mm., the image of the slit would be diminished to about $^7/_{10}$. Hence the slit can be made in the one case $^5/_3$ in the other $^{10}/_7$ the width with the present spectrograph and

have the lines of the same width, and consequently equally accurately measurable. The gain in efficiency is thus about equal under the latter consideration and that of the maintenance of equal purity, and we may therefore consider that a decided advantage may be obtained in stars of all types by increasing the aperture of the prism. Such conclusions are, of course, subject always to the test of actual use under similar external conditions before they can be accepted as final.

However, some experiments that I made here last winter on the effect of widening the slit upon the accuracy of velocity determinations* substantiate the above conclusion, and I will therefore give a short summary of some of the results reached. As previously stated, when the slit is widened, the purity is diminished and the lines become broader and more diffuse. To simplify the investigation, the question of the effect of purity was eliminated by choosing a star, *β Orionis*, for the test whose lines are single and moderately sharp. There remains, then, only the question of the effect of the increasing breadth and diffuseness of the lines on the accuracy of the measures. Evidently such a question can only be settled by making and measuring a number of spectra at each slit width. Six plates were made for each slit width 0·025, 0·038, 0·051, 0·076 mm. for two dispersions, (*a*) single-prism, 525 mm. camera, (*b*) three-prism, 525 mm. camera and six each at slit widths 0·025, 0·051, and 0·076 mm. for a dispersion of three prisms and camera of 275 mm. focus. In all 66 were made, of which I have to thank Mr. Harper for measuring 18 and thus lightening the considerable labor involved. Owing to the different dispersions, different lines were measured in the three sets, but as the main dependence can be placed on the three lines, *Mg* 4481·400, *He* 4471·676, and *Hγ* 4340·634, the results from these three lines only are given. Computations using all the star lines measured were also performed without, however, changing the conclusions reached.

There are evidently two kinds of error to be considered, accidental and systematic. Under the first will be considered

*Since published in the *Astrophysical Journal*, Vol. XXVIII., p. 259.

the accidental errors of the setting of the microscope wire on the individual lines in a plate, resulting in a mean velocity for that plate differing from the true velocity in a greater or less degree depending upon the quality of the lines. The systematic error of a plate is the displacement of the star lines as a whole with respect to the comparison lines. This may be due, as previously stated, to one or more of several causes—change of temperature, flexure, faulty adjustment or aberrations in the optical train, etc. As the lines are in general equally affected, such displacement will not be apparent in the measure of a single plate. It is only by comparing the velocities of a number of plates of a star of constant velocity that such an error can be detected.

To compare the accidental errors for the different slit widths it will be necessary, to prevent systematic displacements from affecting the result, to treat the measures for each of the six plates for one slit width separately, to obtain the residuals from the mean velocity of each plate and finally the probable error of measurement of an average star line from these residuals. Some idea of the relative magnitude of the systematic errors may be obtained by treating the velocities from each of the six plates. However, this result will not be that due to systematic error only as the velocity from each plate will also be affected by accidental errors. The results of the measures and computations are given below.

PROBABLE ERRORS

Dispersion	Slit Width	Accidental	Systematic
		Prob. Error, Average Line	Prob. Error, Single Plate
Single Prism.	0·025	± 4·5 km.	± 1·7 km.
	·038	2·4	2·7
525 mm. Camera	·051	2·3	3·0
	·076	4·3	7·7
Three Prisms	0·025	± 2·3	± 1·5
	·038	2·1	1·3
525 mm. Camera	·051	2·5	0·7
	·076	2·1	0·9
Three Prisms	0·025	± 2·9	± 2·1
	·051	2·9	3·0
275 mm. Camera	·076	3·8	2·9

These results were to a considerable extent unexpected. The great difference in the apparent quality for measurement of the spectra made with slit 0·025 and 0·076 mm., especially with the single prism, would lead one to expect a marked increase in the errors of setting, but this is not very distinctly shown, not at all in the higher dispersion. The systematic errors, however, are very markedly increased in single-prism plates, so much so as to prohibit the use of slits wider than 0·051 mm. In a higher dispersion spectroscope this increase has disappeared and, so far as the rather small number of plates show, it is slightly more accurate in the case of dispersion (*b*) to use slits 0·051 and 0·076 mm. than slits 0·025 and 0·038 mm. It is evident that these corroborate the conclusions previously reached, by showing that increase in resolving power removes or diminishes the loss of accuracy when the slit is widened. Consequently with the 50 per cent. greater resolving power and the 60 per cent. greater ratio of collimator to camera focus, it is probable that the slit width may be increased 50 per cent. without affecting the accuracy of the results and with a corresponding increase in the output.

Mechanical Design.

The question of the most favorable dimensions of the optical parts having been discussed, there remains the mechanical structure connecting these parts into one stable whole. Owing to the attachment of the instrument to a moving telescope and the consequent varying direction of gravity on the parts, the prevention of flexure is one of the most difficult of the problems to overcome, and this is especially the case where the instrument is to be attached to a telescope of moderate size, where its weight can not exceed a certain small limit. The weight of our spectrograph complete, with temperature case, attaching truss, etc., can not much exceed 100 lbs., and the problem is consequently a much more difficult one than in the case of the Yerkes equipment for example, where the spectrograph weighs about 500 lbs. Most of the early and some of the recent spectrographs have lacked sufficient stiffness and stability to prevent line displacements due

to flexure of the parts. A displacement of the camera and plate of only one one-thousandth of an inch is equivalent in a single-prism spectrograph to a velocity of about 50 km. per second. It is evidently a difficult matter in the extended form of a single-prism instrument to reduce this flexure to an inappreciable amount. No material is perfectly rigid and when we consider that even its own weight deforms the strongest material available the difficulty of the problem will be realized.

Until very recently all spectrographs were attached to and overhung the end plate of the telescope and thus, like a beam fixed at one end, were subjected to the maximum amount of flexure. An improvement in the principle of attachment was applied at the Lick Observatory recently in which the spectrograph proper is made self contained and is held in an independent cradle at two points of support. It is thus like a beam supported at both ends and the flexure is therby much reduced.

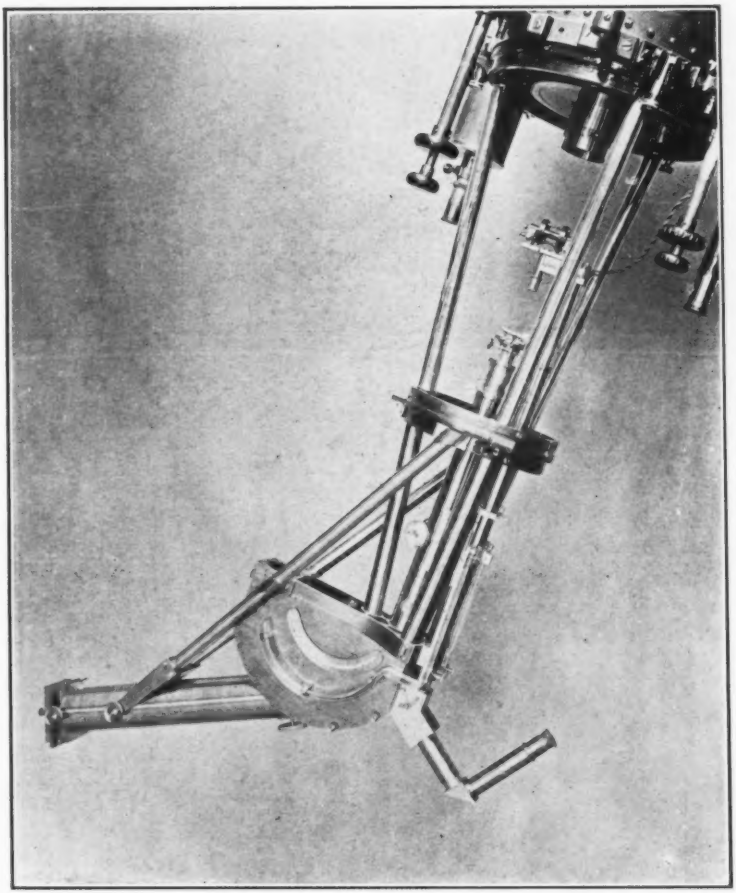
The original spectroscope belonging to the Observatory was by Brashear of an adjustable universal type and was not, for this very reason, suitable for radial velocity determinations. Braces were added to stiffen the frame as much as possible but it could not be freed from flexure. Many of the results obtained were uncertain and its use was discontinued as soon as a new combined one- and three-prism spectrograph, designed by myself and very satisfactorily constructed by Mr. Mackey in the Observatory workshop, was completed.

This instrument, whose general form is readily obtained from the plates (IX. and X.), has many original features, has given excellent satisfaction and produced reliable results. It is, as will be noticed, a form of the first class mentioned attached only to the end plate of the telescope. It was designed and partly constructed before anything was learned of the new type. Moreover, it was desired, for the sake of economy of time and money, to combine single- and three-prism instruments in one (since found by experience to be a mistake), and this could not be advantageously effected in the new form.

PLATE IX.

THREE-PRISM FORM OF THE OTTAWA SPECTROGRAPH

PLATE X.



ONE-PRISM FORM OF THE OTTAWA SPECTROGRAPH

The form of truss designed has some advantages over previous instruments, and has probably less flexure than any other of the same type and weight. The main difference lies in the close grouping of the triangular truss at the lower end and the addition of the substantial diagonal brace, which serves the two purposes of stiffening the outer end of the prism box and lower end of the camera when used in three-prism work (Plate IX.), and of tying the outer end of the camera when used with a single prism (Plate X.) The maximum flexure of the three-prism instrument is equivalent to 1·8 km. only, while the maximum flexure of the modern Bonn three-prism instrument, the only one for which data have been published, is about 70 km. For an hour's exposure with the Bonn instrument there is a flexure of 7 km., while a similar exposure with both single- and three-prism forms here shows no appreciable flexure. The maximum flexure with our single-prism is much greater—about 100 km., equivalent to a linear displacement of about $^1/_{400}$-inch. This great difference in the two forms is due to two causes. First, to the threefold greater kilometre value for the same linear displacement. Second, to the much more extended form of the single-prism instrument. Calculations have shown that the amount of flexure is nearly that caused by the actual extension and compression of the truss members due to their own weight, and consequently it can not be avoided or much reduced in this form of inrtrument. However, the flexure occurring during a two hour exposure is only slight except at such great hour angles as are rarely used.

Both forms of instrument are frequently required on the same night, for stars of varying brightness and type. The time lost in making the change from single- to three-prism or *vice versa* and the uncertainty in the temperature conditions prevailing after the change, close temperature regulation being equally as important, perhaps more important than avoidance of moderate flexure, were considerations leading to the decision, which had the approval of Dr. King, to design and construct a separate single-prism spectrograph, with separate temperature control and

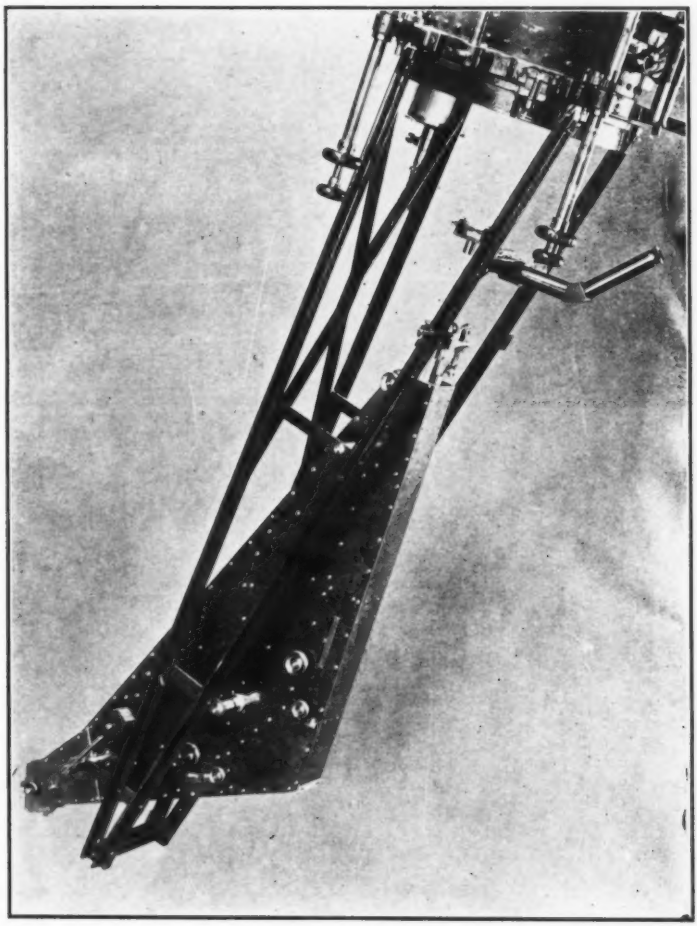
attaching stand so that the change could be made in a minute or two and without disturbance of temperature.

Besides using a larger prism for the reasons fully entered into above, the opportunity was taken of changing the mode of attachment to the telescope. Curtiss of Ann Arbor designed a form of single-prism instrument modelled after the Lick pattern, which has two points of support, one near the slit and the other near the base of the prism. The spectrograph proper consists of a triangular brass box with angles of about 120°, 30°, 30°. The prism is at the obtuse and the slit and camera at the acute angles of the triangle. The camera end hangs out unsupported and flexure will still occur though in a much diminished degree.

The form I have designed and am now having constructed in the workshop follows that of Curtiss in that it is of the box form, but the design and construction of the box and the method of attachment to the telescope are different. The box is made of hard cast steel plates (saw steel) much stiffer than brass, is rigidly braced and cross braced, and is provided with three points of support in a cradle of T iron attached to the end plate of the telescope (Plate XI.) Two of the points are similarly situated to those of Curtiss, while the third acts near the camera end. The two first are attached by a kind of universal joint, so that no strain can be induced in the box by any bending of the cradle. The third support, near the camera, consists of a pair of counterbalancing levers, one on each side of the box, arranged to equalize the pressure on the three supports in any position of the telescope without it being possible to ever induce any strain in the box itself. By this means it is believed that no measurable or even noticeable flexure will occur.

A simple triangular box of this form without projections of any kind is much more readily adapted for temperature regulation than the complicated shape of the regular truss form. Moreover, any stratification in the temperature case is much less likely to occur, and if it does, can not do nearly so much harm as if it were acting on only one member of the truss. A further improvement will be the introduction of a non-conducting mate-

PLATE XI.



THE NEW SINGLE-PRISM SPECTROGRAPH OF THE OTTAWA OBSERVATORY

Journal of the Royal Astronomical Society of Canada, 1909.

rial such as vulcanized fibre in the supporting arms between the cradle and the box, so that heat will not be conducted away at these points and unequal temperature and possible distortions take place.

In the present spectrograph, conduction through the arms of the truss is so great as to cause a gradual drop of the temperature in the prism box, as the outside temperature falls, of about 0·1° C. every one or two hours. The distance between the spectrograph box, which will be entirely covered with thick felt, and the inside of the felt lined outer case will be uniform, the heating wires will be uniformly distributed and consequently little difficulty with inequalities of temperature should result.

Although until the instrument is completed and tested, no definite statement can be made, I have little doubt that the new spectrograph will be a considerable improvement over the present or any existing single-prism instrument.

In conclusion I wish to express my obligation to Dr. King, the Director of the Observatory for his ready consent to the construction of the new instrument and for his interest in the work.

HALLEY'S COMET AND ITS APPROACHING RETURN

By A. D. Watson

WHEN the cooling fire-mist took shape out of the primeval storm, and whirling orbs found permanent orbits, and luminous atmospheres caressed the slowly-forming satellites and hovered around the mightier planets, vast masses of matter were left afloat in the uttermost parts of the solar system. Their number was, and still is, inconceivably great. These masses after cooling would take the form of planets, large or small, and move in harmony with all the laws of celestial motion along their distant orbits. Their movements were slow because of their distance from the Sun.

It is impossible to doubt that many of these interesting bodies are larger than the earth. Besides these great planetary masses, there are smaller bodies in sizes varying from that of the smaller planets down to that of the finest particles of dust. Some of these masses, especially the larger ones, have probably their own atmospheres.

These smaller bodies and particles are not confined to the outer regions of space alone, but are found at all distances from the Sun even to its very surface. They are unseen by us except when they happen to strike our atmosphere, when friction makes them incandescent, and we then call them meteors.

Out of these smaller bodies, in the great laboratory of nature, was Halley's comet compounded. Various attractions resulted in the forming of groups which, segregated for a time, met, at length, with sharp collision and changed the orbit finally into a long ellipse with a direction almost precisely sunward.

There is no doubt that such a comet as Halley's is composed of a great agglomeration of world-stuff that was collected thousands of years ago as the result of the attractions and repulsions

of its various constituent parts, that these loosely combined parts and particles have formed a nucleus consisting of the largest of its components, that its smaller particles are floating in gases, uniform chemically with the substances which they envelop, and that the tail, which is present only when the comet is near the Sun, consists of particles of dust floating in the cometary vapors.

Our young comet, Halley, having been gathered by many attractions, repulsions, perturbations, deflections, etc., into a somewhat definite cosmic coherence, obeyed the irresistable call of the Sun, approached slowly, sailing down through the far, silent ways, passing through wide spaces where to us no objects are visible. Yonder were Neptune, Uranus, Saturn and Jupiter, moving like satellites around the Sun.

And now our swarm of meteors with its enveloping vapors having passed the outer planetary orbits, with accelerated motion, swept down amid multitudinous worlds. When it neared the paths of Mars and earth, a new wonder was seen. A long train of dust and vapor was beginning to develop, was stretching afar into space till men on earth, if there were any, saw imaged there an avenging angel, with sword drawn to wreak terrible vengeance on the sinners of those times.

The comet bore down with incredible swiftness till it reached its perihelion position, its cometary tail standing out opposite the Sun. Then began its departure, and once more it sailed out among the planets, its tail in advance, and always pointing away from the Sun, till at last beyond Mars and the asteroids, this appendage disappeared, and the comet gradually slowed down and moved out with stately motion to where Jupiter was approaching in his path. The great comet was about to leave the solar centre never to return, but Jupiter seems to have used such persuasive attractions in the case of this visitor with the glorious hair, that she was induced to return, and brought her course into accurate relation to that purpose. So it happened that some seventy-five years later she was again found in the house of Jupiter on her way to the home of the Sun.

Since then this gigantic body has visited the Sun about every seventy-six years.

It is said to have signalized, in 130 B.C., the birth of Mithridates, when it "surpassed the Sun in splendor and its tail extended over one quarter of the firmament."

It appeared again in 87 B.C.

In 11 B.C., "it was suspended over Rome like a flaming sword for several weeks, prior to the death of Agrippa."

In 66 A.D., it hung over besieged Jerusalem.

An observation of it is recorded in 240 A.D.

"In 399 A.D., its return was specially spectacular," and it is described as "A comet prodigious in magnitude and terrible in appearance."

Reappearances are recorded also in A.D. 467, 550, 684 and 930. Up to this point, as will be seen by the irregularity of the periods, the records are more or less unreliable, but subsequent records are authoritative.

It celebrated the Norman conquest by a return in 1066, and was again seen in 1145.

In 1222 it was supposed to foretell the death of Philip Augustus.

In 1301 its appearance was very remarkable and it was seen again in 1378.

Six perihelions have been recorded since :—

June 9, 1456,
August 24, 1531.
October 16, 1607,
September 4, 1682,
March 13, 1759,
November 16, 1835,

and we may add here that its next return is expected in April, 1910.

The appearance in 1456 was most extraordinary. Its tail extended over 60 degrees, and was seen throughout June of that year.

In 1531 it was observed by Appian, in 1607 by Kepler, in 1682 by Halley.

Edmund Halley was a friend of Sir Isaac Newton, on whose advice he investigated the possibility that comets return periodically, a daring hypothesis in those days. He examined records of 425 comets up to the year 1700. In twenty-four cases observations had been made with sufficient precision to help him in his calculations. He found that the paths of the comets appearing in the years 1456, 1531, 1607 and 1682 corresponded with an approximate period of 75½ years, but found also that the planets by the force of their attraction exerted a retarding or accelerating influence on the velocity of the comets. Halley being convinced that these were one and the same comet and that it would return in 1758, published his prediction to that effect. "If it should return," said he, "according to our prediction about the year 1758, impartial posterity will not refuse to acknowledge that this was discovered by an Englishman."

The mathematician Clairaut, of Paris, undertook to make the necessary elaborate calculations to ascertain the comet's next perihelion period. He was assisted by Lalande, who says: "During six months, we calculated from morning till night, sometimes even at meals, in consequence of which I contracted an illness, which changed my constitution for the remainder of my life. It was necessary to calculate the distance of Jupiter and Saturn from the comet, and their attraction upon that body, separately for every successive degree, for 150 years."

Uranus and Neptune were as yet undiscovered, consequently their disturbing influence was not taken into account, and the action of the earth was not considered. The mass of Jupiter was not accurately known. Clairaut's final prediction for the perihelion passage of the comet was for April 4, 1759. It is interesting to note that he affirmed at that time that the gravitation of an unknown planet beyond Saturn might act on the comet.

Although all the astronomers of the world of that day were alert, it was a peasant named Palitzch, of Dresden, Saxony, who, on the night of Christmas, 1758, first saw the comet. It

arrived at perihelion March 13, 1759, 23 days before Clairaut's predicted time. Its appearance was globular with a brilliant nucleus, and without a tail. It disappeared about the first of June.

The next and latest appearance of Halley's Comet was in 1835, when it came to perihelion November 16, having been predicted for November 14, an error of only two days in seventy-six years. On this occasion it was first observed at Rome, and resembled at the time of its discovery a faint nebulous mass. On September 21 the nucleus was as bright as a sixth-magnitude star. By October 3 it was as bright as a star of the fourth magnitude. On October 12 the nucleus was distinctly visible to the naked eye, and the tail was six degrees in length.

Owing to possible perturbations of the comet by Jupiter and other planets, many conditions of uncertainty are introduced, which are liable to disturb or modify the realization of our expectations in reference to the next return of Halley. When we speak of the recurrence of an eclipse after the lapse of a metonic cycle, we calculate the necessary modification with a good degree of accuracy, foretelling the eclipse with confidence that our predictions will be realized, but when dealing with a comet of long period, its tenuous and almost amorphorus constitution, its comprehensive orbit, and its long period, offer a great many opportunities for change of form, disturbance of course, or even of deflection into an entirely new orbit by other bodies of great mass and attractive force. All the predictions, therefore, in the present case are contingent upon the absence of disturbing factors some of which are not ascertainable, but which may nevertheless chance to be active on this occasion in Halley's orbit. The planets, whose substance is comparatively more rigid, and whose periods are briefer, are not subject to so many disturbing influences, and we can speak of their motions beforehand with more assurance.

We may be sure that unless some quite unlooked for circumstance has resulted in an entire change of its course, Halley will soon be seen by some telescopic eye in the borders of Taurus or

Gemini after the photographic plate has established its position.

For many years this comet has been travelling below the plane of the earth's orbit and it is unfortunate that during its present approach, while in proximity to the earth, it is not likely to be above our horizon at night during much of the time. At its last appearance its usual brilliancy was not attained. No tail was visible for some time after its first appearance. The absence or shortening of the tail may be due to the loss of matter while travelling near the Sun in its many perihelion periods. This is easily understood when we consider that no portion of the matter contained in a cometary tail ever returns to the body of the comet, but is distributed into space along or near to the comet's orbit. Another influence that lessens the brightness of a comet during some of its perihelion passages, is the proximity of a sun-spot minimum, indicating a lessening of the solar energy. For while the fact, that a comet's tail always points away from the Sun is due chiefly to radiation pressure, there is little doubt that the repulsion is attributable in a considerable degree to the influence of electric conditions. The stronger the electric energy of the Sun, *cæteris paribus*, the greater the length of the tail.

J. J. Thomson (*Proceedings of the Royal Society*, LVIII., No. 350) has shown that if *H*-gas is electrified positively, the green line in its spectrum will be brighter than the red, and, on the other hand, if negatively electrified, the red will be brighter than the green. In the case of the Sun, however, the red is the brighter line. We may therefore infer that the Sun's surface is charged negatively. If the ultra-violet rays of the spectrum be allowed to fall on a metallic body, little corpuscles or electrons leave the atoms forming the metallic body and fly away from them with enormous velocity. These corpuscles either carry a negative charge or else themselves constitute the negative electricity, are repelled by the negatively charged Sun, and recede from it. Thus the electrical conditions act conjointly with the effects of light pressure in explaining the fact that the comet's tail always points away from the Sun no matter whether the head of the comet is approaching or leaving that body. As soon as

the sphere of the Sun's electrical influence is passed, the tail disappears till the comet comes once more within that sphere of electrical influence.

If this reasoning be true, it explains to some extent the very moderate brightness and length of the tail of Halley's Comet in 1835, for in that year the Sun's activity was very mild as shown by a sun-spot minimum near the date of Halley's perihelion passage. We know, indeed, that comet's tails like auroras are most vivid during years of greatest sun-spot activity. Unfortunately for our prospect of seeing a very brilliant comet next year, we are again near a mild period of solar activity and the result may be the same as in 1835.

It was after its perihelion in 1835 that the greatest brightness was seen on that occasion, and this is almost certain to be the case next year. In the pre-perihelion period there will be probably little opportunity to see the comet from northern latitudes, and we can hardly expect to see it by day, though on some former occasions it was visible in broad daylight.

On January 6, 1910, it will be about half way between *Beta Arietis* and *Alpha Piscium*. It passes slowly westward and will cross the ecliptic from south to north latitude shortly afterwards. It will remain in the constellation of Pisces throughout February, but in the early days of this month it ceases to be visible, being too near the Sun. On March 23 it will become a morning star, passing westward about six degrees north of the Sun.

It will be in perihelion on April 16, and on April 20 will be two hours west of the Sun and rapidly getting brighter. On May 2 it will be about a degree north of *Omega Piscium* and will then begin to travel eastward. On May 8, the day of the total eclipse of the Sun, the comet will set twenty minutes before totality occurs, but as this affects only the southern hemisphere, it need not concern us here. It will then be thirty-four million miles from the earth.

On May 14 it will rise more than an hour before the Sun and should be clear and conspicuous in the early morning. The tail will point westward towards the meridian. It will now

travel rapidly eastward to its conjunction with the Sun, about three degrees south, on the morning of May 17, but on May 18 it will be far east of the Sun, about half way between *Beta Tauri* and *Beta Orionis*. This will be its time of nearest approach to the earth (twelve million five hundred thousand miles).* The tail will extend across the southern part of Gemini and should be an object of great interest, if not of real splendor. The Moon's brightness at this time may, however, be some impediment.

On May 19 the comet will be near *Zeta Geminorum*, on the 20th three degrees north of *Beta Canis Minoris*, on the 21st four degrees north west of *Beta Cancri*, and on the 22nd one degree north of *Delta Cancri*. The distance from the earth will then be twenty million miles, and its brilliancy will be rapidly decreasing.

It will cross the ecliptic May 16, thirteen million miles within the earth's orbit, and 80,000,000 miles from the Sun, 2½ days before the earth reaches the same node.

On June 2 it will cross the equator 13 degrees south of Regulus.

It is said that cometary matter has been known to acquire a velocity of 22 hundred miles per second, and it is possible that meteors thrown off by Halley may reach our atmosphere about May 5. It is not likely to disturb our health, however, and none need fear evil effects from the approach of this tremendous adventurer of the skies.

All our comets belong to this solar system. How do we know this? If it were otherwise,—if some of our comets came out of the interstellar spaces beyond our solar system,—many comets would reach us from the direction of Lyra, towards which our system is moving, and these would approach with far greater speed than those which came from any other direction, but we

*Since this paper was read, the astronomers at Greenwich Observatory have predicted Halley's perihelion date as April 8, 1910. This, if correct, will modify considerably the predictions mentioned in this article. The distance from the earth is also reduced to seven and a half million miles, and the date of nearest approach is given as May 12.

find that very few comets reach our Sun from the direction of Lyra, and those which do approximate that direction, have no velocity not accounted for by the theory that they are an integral part of our solar system. Our comets and our planets all participate in the on-go of the particular order to which they all pertain. They are all our own, and belong neither to Sirius nor to Vega, nor to Antares, nor to any star other than our Sun. No matter whether they are periodic, and therefore moving in elliptical orbits and returning at stated intervals, or unexpected, and therefore never returning to the solar centre—all are ours whether Swift, or Donati, or Biela, or Tempel, or Olbers, or Halley. There is world-stuff in abundance in the space beyond Neptune's path. Multitudes of orbs larger than ours, that no camera can ever sense, no telescope can ever image, are still moving in that belt of silence which to our eyes is as if it were not. They are of the same constitution as the comets, the meteors, Saturn's rings, the volcanic stream that pours out of Pelee, the heated dust through which the level beams of the Sun shine, and which refract the evening light and make our glorious sunsets. Combine our dusty city air with our great terrestrial aurora, and what is our own earth but a modified comet, with a steady motion, a very pretentious population, and a very unpretentious cometary tail?

We never see ourselves as others see us. We did not know that the earth reflected sunlight onto the Moon, which we can see on its darker portion, till Leonardo di Vinci told us we had been looking at it for ages.

There are few of us who get any unified concept of the universe. And yet our universe is also diverse, our comets, as expressions of universal law, are a far call from our planets, and still farther from our Sun, nevertheless the same laws are operative in all cases and no particle of matter, whether it be a speck of dust in the tail of a comet, or a blazing sun dominating a great system at the centre of the cosmos, can escape the great universal laws which Copernicus and Galileo, Kepler and Newton, have brought to light.

Some of the greater comets in ancient times were regarded as angels with drawn swords, and many superstitions are suggested by the annals of these wonderful and somewhat difficult apparitions. Tycho Brahé first showed that comets were independent celestial bodies and not mere terrestrial portents, a part of the earth's atmosphere. Newton proved them to be subject to gravitation, but did not understand what Clark Maxwell has recently explained, viz., the fact that their tails are always opposite the Sun.

Schiaparelli and others have drawn attention to the fact that our meteoric showers of August 10 and November 14 were due to great swarms of meteoric bodies moving in elliptical orbits, practically coincident with the orbits of two well known periodic comets (Tuttle's 1862 and Temple's 1866).

It is now known that meteors may be collected into comets and that comets may be disintegrated into meteors.

Will not a comet some day strike the earth? May not such a catastrophe be the cause of the end of the world? Yes, it may be so. A great comet no doubt would have serious effects if it did collide with so small a planet as ours. It would at least poison the atmosphere in all probability. But let us take comfort in the fact that "Considering the vast recesses of celestial space and the insignificant size of our earth, the probability of such an encounter may well be likened to the chance that if a man should shut his eyes and fire a gun into the air, he would bring down a bird."

ATMOSPHERIC CIRCULATION

By R. F. Stupart

THE astronomer Halley in 1686 enunciated the theory that as the temperature of the air decreases from the equator to the poles, there ought to constantly exist an upper wind or equatorial current blowing from the equator to the poles and a lower wind or polar current blowing from the poles to the equator. This theory was supplemented by Halley in 1735 by the statement that whatever be the direction followed by an atmospheric current the earth's rotation deviates this current to the right in the northern hemisphere and to the left in the southern hemisphere.

Halley's theory seemed reasonable, but as observation showed that the general drift of the atmosphere in the middle and higher latitudes is from the westward, it became necessary for the more modern meteorologist to find directly what are the true movements of the atmospheric currents and then formulate a theory in accord with ascertained facts.

The earliest data available regarding the circulation of the upper air, based on cloud movements, was provided by many keen observers, among whom the Rev. Clement Ley of England and Professor H. Hildebrandsson of Sweden stand pre-eminent. Further and still more conclusive data as to atmospheric movements have been obtained within the past few years by means of kite and balloon, and among the most energetic investigators were Professor A. Lawrence Rotch of Boston, Mass., and M. Teisserenc de Bort of Paris, France.

In a zone near the equator—a zone encircling the globe and comprising the region of highest temperature and which oscillates northward and southward, moving always with the Sun—observations show that the atmospheric currents at every height and almost without exception are from east to west.

North and south of this equatorial zone, approximately to latitude 35°, are found the steady persistent northeast and southeast trade winds, the prime factor in producing the great ocean currents, and above these trade winds there prevails an anti-trade from the southwest in the northern hemisphere and from the northwest in the southern. Beyond the trade-wind zones, over the middle latitudes, the prevailing drift of the atmosphere is from west to east, and with this atmospheric drift move the cyclonic areas which lead to the summer shower as well as to storm and rain and snow. Charts of barometric pressure indicate that the whole wind system of lower latitudes is directly connected with pressure conditions, there being a belt of low barometer readings around the globe in the equatorial zone, and belts of high barometer readings to the northward and southward, the whole system having an annual oscillation with the changing declination of the Sun.

The tropical belts of high pressure have sometimes been explained as a result of the crowding of the upper currents from the equator advancing along the converging meridians, but this can only be in part correct, for if the convergence of the meridians determined an increase of pressure, the pressure should be highest at the poles, whereas it is highest between latitudes 30 and 40.

Observation has shown pretty conclusively that the equatorial currents in the upper regions turn away to the eastward in the direction of the earth's rotation and form a continuous whirl around the earth over all the higher latitudes, and it is now believed that the high pressure which should result from the low polar temperature and the shape of the earth, is reversed into low pressure by the forces which lead to the circumpolar whirl, and the air thus held away from the polar regions is found in the tropical belts of high pressure.

The distribution of continent and ocean tends towards complexity. As land absorbs the solar heat much more rapidly than does the ocean and conversely parts with heat more readily, the range of temperature between summer and winter of continental

areas is vastly greater than over the ocean, and the circulation of the atmosphere near the earth's surface is in consequence greatly modified by land and sea.

The most marked evidence of this is found in southern Asia, where with great heat in summer is situated the lowest barometric pressure of the northern hemisphere, which leads to the southwest monsoon of the Indian Ocean, and which is indeed the southeast trade wind deflected to the southwest after passing to the northward of the equator. In winter, on the other hand, over the great land area of Asia is found a vast anticyclonic system which may perhaps not unreasonably be regarded as a portion of the extra tropical pressure drawn northward and intensified by the contraction of the atmosphere owing to low temperature, and leads to the northeast monsoons of the Indian Ocean and China Sea, which are closely related to the northeast trade winds of Atlantic and Pacific.

It is clearly evident, however, that while the effect of continent and ocean is far reaching, it is but one of several factors governing the atmospheric circulation. The fact that the highest winter barometric pressure in Asia is found far south of the greatest cold, together with the general appearance of the chart of mean pressure, suggest that the factors which lead in general to the extra-tropical belts of high pressure are predominant. In the southern hemisphere, with a vast preponderance in area of the ocean over land, the extra-tropical higher pressure belt is more continuous and persistent throughout the year, merely changing its position with much regularity with the changing declination of the Sun.

As yet it is not known why the atmospheric circulation varies somewhat from year to year. It certainly does vary and this variation may be sufficient to wholly account for the changeableness in the character of corresponding seasons in different years. Investigation of the solar radiation, together with barometric gradients and wind velocities in the tropics, may not prove abortive.

An interesting problem, now receiving attention in the Meteorological Office, is that of the formation of anticyclones in the higher latitudes. It seems not improbable that these anticyclones represent the coming to earth of branches of the great equatorial overflow, and it is important to investigate the connection between them and pressure changes and wind movements in the tropics.

MEETINGS OF THE SOCIETY

At Toronto

May 4.—The paper for the evening was by Dr. A. D. Watson on "Halley's Comet and its Approaching Return." A full account of the paper is found in this issue (p. 210).

The address was followed by an interesting discussion in which Messrs. Muir, Miller and Musson took part. Mr. Muir asked a question respecting the spectroscopic observation of comets, and Mr. Miller gave his experience. Mr. Muir stated that one of our members, Mr. Elvins, remembers the last appearance of Halley's Comet. Mr. Miller kindly offered to give a demonstration with the spectroscope before the Society in the near future.

May 18.—The following were elected members of the Society :—

Miss L. G. Causey, Toronto.

Stanley Johnstone, Toronto.

I. R. Pounder, Toronto.

These were read for the second time and the election duly completed. It was explained that the first reading of the nominations of Mr. Johnstone and Mr. Pounder took place some months ago, but that owing to some accident the elections had not been completed.

The address was by Mr. H. P. Mills, B.A., on "Terrestrial and Stellar Temperatures." Mr. Mills gave a history of the development of instruments for the purpose of determining temperature, and described the methods followed in constructing and the characteristic features of many different instruments. This was followed by interesting information respecting the determination of the amount of heat radiated by the stellar bodies. The

lecture was illuminated by many lantern slides and a most elaborate and valuable collection of different classes of thermometers and apparatus. At the close, Mr. Muir expressed the Society's appreciation of Mr. Mills' very interesting address and of his trouble in collecting and explaining so many seldom-seen instruments.

E. A. D.

At Ottawa

April 15, 3 P.M.—Two papers were given, the first by Dr. O. Klotz on "Gravity at Sea," the second by Mr. J. S. Plaskett on "The New Single-Prism Spectrograph."

In the limited time at his disposal Dr. Klotz did not attempt to give an account of the details and niceties of the observations for gravity at sea, but rather aimed to make clear the principles upon which the method for obtaining gravity is based.

The idea of determining the change of gravity upon the earth, by measurement of the relative and absolute pressure of the atmosphere is not new, but the successful carrying out of such determinations was accomplished only recently. If the aneroid barometer with its mechanism were thoroughly reliable, and if it were adjusted to read the same as a mercurial thermometer for a given latitude, then for any other latitude the difference of the readings of the two barometers, after the usual corrections for temperature had been made, would indicate the change in the force of gravity as affecting the mercurial barometer, inasmuch as the weight of the mercury column necessary to balance a given atmospheric pressure would change with change of latitude, while a given pressure would be indicated by the aneroid with the same reading quite irrespective of latitude.

For the unreliable aneroid was therefore substituted the "boiling thermometer," as the boiling of water is independent of latitude, it is simply finding the temperature when the vapor tension equals the atmospheric pressure. The standard pressure of one atmosphere is taken at 760 cm. of the mercurial column at 0° C. and at latitude 45°; and when water boils at this

pressure the thermometer scale is adopted as 100° C. As the extreme range of gravity between the equator or pole to latitude 45° is only 26 mm., which would be represented by about 2·2 mm. difference in atmospheric pressure between the boiling thermometer and mercurial barometer, it is seen that the extreme difference of temperature consequent to the difference of absolute or relative pressure is ·08 C. or about one-seventh of a degree Fahrenheit, which shows with what extreme care the observations must be made if they are to have any value.

Dr. Klotz then described the special marine barometer, the photographic method of recording the height of the mercury columns, the apparatus for obtaining the temperature at which water boils and the methods of setting up these instruments in order to counteract as far as possible the movements of the ship. He also described the special apparatus used to record the movements of the ship and the corrections to be made for such movements. Slides showing the different apparatus were shown.

In conclusion Dr. Klotz spoke of the work of Professor Hecker in determining gravity at sea. The results showed gravity to be fairly normal and to conform to Helmert's formula of 1901 ; they also tended to confirm Archdeacon Pratt's hypothesis of isostatic layers of the earth's crust.

After the lecture was over, Dr. Klotz was asked by one of the members to give an exposition at some future meeting of the action of the barometer in regard to approaching storms. Dr. Klotz kindly promised to do so.

Mr. Plaskett then spoke on the new single-prism spectrograph. The lecture was along the lines of the one given by Mr. Plaskett about a year ago, when he spoke on the principles involved in designing the most efficient type of spectrograph embodying the results of investigations recently undertaken.

Mr. Plaskett spoke first of the optical design of the spectrograph. The aim was to obtain a maximum of exposure and this was done by increasing the size of optical parts up to a certain limit. This limit was obtained partly by experiment, and partly by calculation. In the instrument under consideration the prism

was a two-inch one, and the collimator of 30-inches focus. The results as regards exposure were better than had been exepected. Mr. Plaskett ascribed this to the peculiarity of the photographic plates, which are more affected by a unit quantity of light acting for 1 sec. than by $\frac{1}{8}$ of that quantity acting for 8 secs.

Mr. Plaskett then showed slides of the universal spectrograph formerly in use at the Observatory and pointed out its defects as regards rigidity ; also the attempts to remedy these by stiffening the framework by braces. As this was not a complete success it was decided to construct another—the one now under discussion.

The fault in the former spectrograph lay in the fact that it was supported from one end and its own weight was sufficient to make it unstable, especially as this weight acted in exactly opposite directions when the instrument was turned through 180°. In the new instrument a cradle was constructed to support the spectroscope box, so that any strains in the cradle, arising out of changes of position, would not cause any strains within the spectroscope box. The box was constructed in the form of a triangular truss and was supported by the cradle at three points. Special means were adopted so that the cradle could not communicate any strains through these three points of support.

To keep the spectroscope at a constant temperature the box was covered with thick felt. Inside were laid silver wires through which an electric current flowed. A device for making the current when the temperature is lowered and for breaking it when the temperature rose was explained in detail by Mr. Plaskett. In practice the temperature could be kept constant to within $\frac{1}{10}$° F. Mr. Plaskett then showed the results of tests of the stability of the new spectroscope as compared with similar tests of the one formerly in use. The tests showed the instrument to be all that could be desired so far as stability was concerned.

Mr. Plaskett, in replying to the comments of Dr. Klotz upon the construction of this spectrograph, drew attention to the fact that much credit was due to Mr. Mackie, the mechanician, for successfully carrying out the designs.

Emergency Meeting, April 27.—The members of the Royal Astronomical Society enjoyed a rare treat when Professor E. E. Barnard of the Yerkes Observatory, and one of the foremost of living astronomers, paid a visit to the Observatory and in the afternoon of Tuesday gave an illustrated address on his recent work. The greater part of his address was confined to that remarkable celestial object that burst forth in the sky last autumn and was named after its discoverer—the Morehouse comet. After its discovery Professor Barnard made it his special study, and watched over it with a devotion like that of a mother over its offspring. Night after night he watched the gauzy visitor in its fickle and capricious movements, and yet if he had been confined to a record of his eyes alone much would have been lost; but photography, that most powerful helpmeet of the astronomer, without which there would be little progress to-day in the unravelling of the beauties and mysteries of the universe, gave the Professor every night indelible prints of the comet. He showed over a hundred slides illustrating the development and evolution of this comet in its mad rush round the Sun. Wonderful, enigmatic were these photographs of this the most remarkable comet, as far as rapid changes in its form and behavior are concerned, that has ever been seen by the eye of man. It appeared to treat with derision many theories that seemed plausible for other comets. Light pressure, gravitation, a resisting medium, electrical and magnetic manifestations, single or combined, failed to satisfactorily explain all the phenomena observed, but, as Professor Barnard says, we have the facts, and the truth must out some day.

After the lecture Dr. Klotz, who presided, extended to Professor Barnard the thanks of the Society for his most valuable and entrancing address. Several stereoscopic views of the comet were afterwards examined by the members in which the comet is seen suspended as a wisp or breath of air far in front of the stars, giving it life, so to speak, and making it an object for intense admiration.

May 1, 8 P.M.—The seating capacity of the lecture room of the Carnegie Library was fully taken up when Dr. Klotz rose to introduce Dr. W. Bell Dawson, F.R.S.C., who was to speak on "The Tides."

Dr. Dawson began his lecture by remarking that a landsman's first impressions of the tide were usually got from the slimy logs, tin cans, and other rubbish left exposed to view when the water receded, and he usually concluded that it was well to be inland and away from the restless sea. But in truth the tide has a soul whose music is the true music of the spheres, the echo of the great sweeping movements of the Sun and Moon. The great regularity of these musical cadences is shown by the tidal curves.

Dr. Dawson then gave a brief review of what history says about the tide. As there are practically no tides in the Mediterranean we have no reference to the tides in the histories of Greece and Rome. But as there is a considerable tide in the Persian Gulf and in the Red Sea the tide must have been noted by the Chaldeans and Egyptians who navigated these waters as early as 2800 B.C. Modern tidal history goes back two or three centuries and is concerned chiefly with the theoretic side of the tides. Newton, Laplace, Lord Kelvin and George Darwin are the most noted names in connection with it.

Before theorizing about tides Dr. Dawson showed what the tide is. The instrument for measuring tides, called the tide guage, was then shown and its workings explained. It consists of a cylinder, rotated by clockwork once every 24 hours, upon which a tracer connected with a float rises and falls with the tide and traces out a curve showing at any moment the height of the tide. A succession of gear wheels reduces the vertical rise to suit the paper used. As the tide rises about an hour later every day each curve comes on the sheet a little farther on than the curve for the preceding day. Hence there is no confusion of curves. Each curve lasts a week.

Dr. Dawson then went on to explain the causes of the tides. The three months of the Moon, synodic month, the month of the

Moon's distance, and the month of the Moon's declination, each had an important influence in determining the character of the tide; and as these months were not of equal length all possible combinations of their individual influences were obtained. It is remakable that while in one locality the influence of one of these months will predominate in another locality the influence of some other one of them will be most prominent, a peculiarity which still awaits a satisfactory explanation. It is this peculiarity which gives us the various kinds of tides in different localities. Dr. Dawson gave striking examples of this from tides in Canadian waters.

Dr. Dawson then discussed the practical work of tidal surveys. At certain points, selected largely by trial, principal tidal stations were established. At these stations continuous records of the tide were kept. A single break in a record of 6 months sometimes made the whole work of little value. From the record of the tides at these principal stations the tide tables for certain points in that region could be deduced. The extent of the region for any particular station was also a matter of trial.

In the discussion at the close of the lecture the question was asked whether the friction of the tides is gradually lengthening our day. Dr. Dawson replied that we have not yet obtained proof that our day is lengthening, and drew attention to the fact that the contraction of the earth in cooling, and the denudation of mountains both tend to counteract any effect which the friction of the tide may have.

A vote of thanks, on the motion of Colonel Anderson, seconded by Mr. Wickstein, was tendered to the lecturer.

May 13, 3 P.M.—Mr. R. M. Stewart, M.A., gave a paper on "Personality in Micrometer Work."

Mr. Stewart first pointed out that when different observers attempt to set a line coincident with a point the results do not in general agree. The reasons for this lack of agreement were of a psychological nature, probably due to the fact that there are two lobes in the brain. The error which thus arises varies with different observers, but is constant for the same observer under the

same conditions; hence in differential measurements, such as measuring the angle between stars of the same magnitude, the errors counteract one another. But if the stars are of unequal magnitude the errors may be unequal, and hence do not exactly counteract one another. The errors also have no effect in measurement of angles on a divided circle, or in micrometer measures with an equatorial or zone observations with a meridian circle, provided the stars observed are all of the same magnitude; on the other hand it will enter into all measures, differential or otherwise, where the objects measured are dissimilar, such as measurement of spectrum lines, or observations on stars of different magnitudes; also into all measures which involve implicitly or otherwise the sum instead of the difference of micrometer readings, such as determinations of azimuth.

Mr. Stewart then discussed the personal error in different classes of observations.

In the equatorial the personal error may vary according to the direction of the line joining the two stars to be measured. Formulæ were deduced to show that in obtaining azimuth the personal error is considerable, amounting to as much as 3″ in some cases. In finding latitude by the zenith telescope the errors balance each other except only when the mean magnitudes of the north and south stars are different. In observations for time, formulæ were deduced showing that for a pair of stars, north and south of the zenith respectively, the personal error vanishes when the zenith distances are equal. If it is not possible to choose a pair of stars fulfilling this condition it is best to restrict the range of the declinations employed, and if the error of bisection is large to correct every set for it.

Mr. Stewart then discussed the methods of eliminating or determining the personal error. The absolute magnitude equation could be determined by means of photography and also by means of diaphragms or screens for shutting off the light of a star and thus reducing its magnitude. The difference of magnitude equation between observers could be obtained by a comparison of observations. The absolute bisection error could be obtained in

a variety of ways by making a second reading with the field reversed ; the difference between the two readings would be double the bisection error. Mr. Stewart then enumerated the ways in which the reversing of the field could be accomplished, and gave the results of experiments actually made by him for each.

The effect of the personal error upon the accuracy of star catalogues was then discussed. In enlarging a catalogue as the added stars were referred to standard stars in their immediate vicinity, the measurements were all differential ones, and therefore were not affected by the personal error. But the systematic errors of the old catalogue would be perpetuated in the new. Mr. Stewart then deduced the formulæ for errors in Right Ascension arising from the personal error, and pointed out that from this cause alone there might be introduced errors large enough to account for the discrepancies in the different catalogues. A catalogue compiled from the observations at many observatories in different latitudes, and extending over a long period, covering the work of many observers, would be fairly free from such effects ; consequently we may conclude that the best existing standard catalogues are fairly accurate. However, a catalogue compiled at a single observatory need not necessarily have large systematic errors, as most of these might be discovered and eliminated, an end to which the efforts of leading astronomers are becoming more and more directed.

C. E.

At Peterborough

March 23.—The regular fortnightly meeting of the Society was held in the Collegiate Institute and proved most profitable and entertaining.

Mr. H. B. Collier, Vice-president, occupied the chair, while Mr. John A. Paterson, M.A., K.C., of Toronto, delivered the main address of the evening on "The Astronomy of Tennyson."

The chairman, in his opening remarks, mentioned a number of the special features previous to the meeting, one in particular being the phenomenon of the appearance of the new moon in an

elliptical form, his brief explanation of this was very interesting to those present.

After the reading and adoption of the minutes the speaker of the evening was introduced. His lecture was decidedly a literary treat.

At the conclusion, a vote of thanks was moved and seconded by Mr. D. W. Dumble and Rev. J. G. Potter respectively, each in eloquent words expressing the extreme pleasure the lecture had given them.

April 29.—The chairman of the evening was Mr. T. A. S. Hay who bespoke the sentiments of the members and others present, when he said that he was sure everyone was delighted to have Rev. Dr. D. B. Marsh, their president, at their meetings again after his protracted illness. Dr. Marsh in a few words showed his appreciation of the chairman's remarks.

The subject of the evening, "Phenomena of the Solar Photosphere," was dealt with in a most able manner by Dr. Marsh, who illustrated his instructive talk with a number of slides, which proved exceptionally interesting to the students of astronomy.

E. F.

At Hamilton

April 30.—Mr. R. F. Stupart, F.R.S.C., Director of the Moteorological Service of Canada, closed the spring term of the Hamilton Centre with his lecture on "The Winds of the Globe." The meeting was one of the successful ones of a successful season.

By means of lantern slides the lecturer first explained the trade winds. The records of barometric observations show that a zone of low pressure exists around the earth's equator, while on either side the pressure is higher. This condition is modified more or less by the positions of the continents and the seasons of the year, still it is generally true. The explanation is that the air at the equator is expanded by the intense heat of the Sun, and becomes lighter. The heavier cool air on either side presses in, causing the heated air to ascend. As it ascends the atmos-

pheric pressure decreases and it expands still more. In expanding it cools and flowing over, as it were, north and south, piles up over the areas of high pressure, and continues the process.

This forms the primary system of atmospheric circulation. The storm centres, which have so much to do with the weather conditions in higher latitudes, Mr. Stupart likened to the eddies seen in a fast flowing stream. He gave as his opinion that these were caused by stray masses of air from the overflow current mentioned above.

The next part of the lecture dealt with the investigations into the state of the upper atmosphere, which are being carried on by means of kites and balloons. Among other things it has been ascertained that the velocity of the winds in these upper regions is terrific, exceeding sixty miles an hour. Speaking of the tremendous forces at work in the atmosphere he showed, by estimating the enormous amount of mechanical work required to produce a moderate shower of rain, how improbable it was that man would ever be able to influence the rain-fall over even a small area.

Coming nearer home he explained more in detail the cause and effect of storms in North America. By means of many weather maps he showed how the storm centres were traced across the continent and how, by a knowledge of their laws, it was possible to predict the weather conditions twenty-four hours or more in advance.

In conclusion he referred to the many uncertainties in the action of these storm centres which made the work of the weather man so difficult. And yet the fact that vessel owners and shippers of perishable goods govern their actions more and more by the advice they receive direct from the department shows that their confidence is deserved. (For a fuller abstract, see page 220).

At the close of the lecture many interesting questions were put to Mr. Stupart bearing on the weather prediction.

E. H. D.

May 29.—The members of the Hamilton Centre spent a delightful evening at the observatory of the vice-president of the Society, William Bruce, J.P., on the mountain top. The meeting had been called for Wednesday (26th) evening, but cloudy weather prevented its being held until the end of the week. The prime object was to give the individual members an opportunity of examining the Moon through the new powerful four-inch telescope which Mr. Bruce has just added to his observatory.

The Moon was ten days old at the time, and one of the principal objects visible on the terminator was the magnificent lunar formation known as Sinus Iridium or Rainbow Bay, which stood out in bold relief between the bright and dark portions of the Moon's surface. Many huge craters were distinctly visible, including Tycho, which is fifty miles in diameter and surrounded by a ridge of mountains reaching a height of 17,000 feet. The rugged lunar landscape, with its innumerable hills and dales was greatly admired by those fortunate enough to view the scene.

The giant planet Jupiter, surrounded with its belt of cloudy matter, was also examined carefully. Three of Jupiter's Moons were visible and the fourth one was found to be in transit across the face of its primary.

Many double stars were looked up, but Mizar, in the Dipper, with its small naked-eye companion Alcor, appeared to be the general favorite, as the telescope revealed two other stars which belonged to this particular system, totally invisible without instrumental aid.

When the members got back to earth again refreshments were served by Mrs. Bruce Walkden, and on behalf of those present the president, G. Parry Jenkins, thanked Mr. Bruce for the great treat they had all so thoroughly enjoyed.

The Elmwood observatory, called after Mr. Bruce's mountain home, is situated in the centre of an eight-acre field owned by him, and consists of the dome formerly owned by Dr. Marsh, to which Mr. Bruce has lately added a reception and reading room, having a flat roof, and outside stairs leading up thereto, for viewing star clusters with mounted field glasses. On one

corner of the deck is a square tower enclosed with glass roof and sides, which provided a safe place for viewing the lightning and storm cloud effects, and underneath the tower is latticed to form a resting summer house.

The observatory is equipped with Jumelle and Lemaire field glasses, mounted on adjustable stands for viewing star clusters on the deck, and downstairs, under the dome, is a fine two-inch telescope with celestial ocular with power of 100, made by Queen, of Philadelphia, also a fine three-inch telescope made by the former president of the Astronomical Society, Dr. Marsh, with Brashear lenses, and a four-inch telescope from the optical works of Sir Howard Grubb, at Dublin, and made under his personal snpervision, the lenses having powers of 45, 110, 250 and 320—a first class instrument, beautifully mounted. Other instruments will be subsequently added.

G. P. J.

NOTES FROM THE DOMINION OBSERVATORY

Astrophysics

The star *β Orionis*, which spectrographically has an interesting history, having been observed at Potsdam, Yerkes and Lick Observatories with varying opinions as to the constancy of its radial velocity, the latter observations tending to show it to be constant, has been under observation by the writer for some time, has been definitely shown to be a spectroscopic binary and the elements of its orbit have been determined. The spectrum is of the Orion and helium type, with lines only fairly well defined and with resulting measures consequently only moderately accurate. The range of velocity is very small, only about 7·5 km., and this, with the uncertainty of the measures, has probably prevented the previous discovery. 275 plates have been obtained on 55 nights, an average of 5 plates per night, and by this means the effect of the accidental errors has been diminished. The elements of the orbit determined by properly grouping these observations are:

Period	$U = 21{\cdot}90$ days
Eccentricity	$e = 0{\cdot}296 \pm {\cdot}059$
Half amplitude	$K = 3{\cdot}771 \pm {\cdot}210$ km.
Longitude of Apse	$\omega = 254°{\cdot}76 \pm 3°{\cdot}48$
Velocity of the system	$\gamma = 22{\cdot}616 \pm {\cdot}158$ km.
Periastron Passage	$T =$ J.D. 2,417,968·80
Semi Axis Major	$a \sin i = 1{,}108{,}900$ km.

Some irregularities in its motion have appeared, but these are discussed in a paper on this star which will shortly appear in the *Astrophysical Journal*.

The star ε *Herculis* $\alpha = 16^h\ 56{\cdot}5^m\ \delta = +\ 31°\ 4'$, announced in 1903 as a spectroscopic binary with possibly composite spectrum, has been under observation here for two years, and from the hundred or so plates secured the orbit has been carefully determined by Mr. W. E. Harper. The velocity curve could not be satisfied by simple elliptic motion. However, a secondary disturbance, with a period one-third the main period superposed on the primary, gave a curve agreeing fairly well with the observations. A least-squares correction, applied by Mr. Harper to the preliminary values, resulted in the elements :

Period	$U = 4{\cdot}0116$ days
Eccentricity	$e = {\cdot}070$
Half amplitude	$K = 56{\cdot}24$ km.
Longitude of Apse	$\omega = 191°{\cdot}65$
Velocity of the system	$\gamma = -\ 29{\cdot}19$ km.
Periastron passage	T = J.D. 2,417,721·334
Half amplitude of Secondary	$K' = 12{\cdot}26$ km.
Time of secondary crossing primary	T' = J.D. 2,417,722·177.

It has been found, however, that the later plates seem to indicate that the period is changing and these elements must be regarded as preliminary only. On about half-a-dozen of the plates the lines of the second component are visible and the star is now being followed closely, with fine-grained plates, to determine the movement of the second component with a view to explaining the irregularities observed in the velocity curve.

A measuring engine, made by Otto Tœpfer & Sons, Potsdam, has recently been received and is set up in the instrument room. It is to be used in measuring the spectra of the Sun, made by the Littrow form of grating spectrograph used in connection with the cœlostat telescope in solar research. Measurements are made by means of a micrometer screw of 0·5 mm. pitch, having a usable length of 300 mm. The micrometer head reads direct to the thousandth and estimation is possible to the ten-thousandth of a millimetre. The microscope is movable on ways parallel to the screw, and a secondary carriage on the main

carriage also moves parallel to the screw and has a slow-motion screw for setting any line of the spectrum to any desired micrometer reading as well as a tangent screw for orienting the plate. The whole instrument is very workmanlike in appearance and convenient in operation. Some plates for the determination of the solar rotation by means of the Doppler displacement of the spectral lines are ready and will be measured immediately.

J. S. P.

THE SEISMOGRAPH—BOSCH PHOTOGRAPHIC, 200 GRAMMES—MAGNIFICATION 120

THE following earthquakes have been recorded since the last notes were sent.

Earthquake in Portugal.

		N–S Component	E–W Component
		h m s	h m s
April 23	Appearance of long waves	18 01 40 G.M.T.	18 03 24 G.M.T.
	End	18 30	18 30
April 24			
	1st P. T.	13 39 08 (?)	13 39 06
	2nd P. T.		13 44 12 ?
	P. P.	13 50 34	13 50 50
	Maximum	13 53	13 54
	End	14 25	14 25
April 25			
	1st P. T.	1 21 10	1 21 18
	2nd P. T.		
	P. P.		
	Maximum	1 27 44	1 28 20
	End	2 00	2 00
April 27			
	1st P. T.		13 03 40
	2nd P. T.		13 15 36
	P. P.		13 41 40
	End		14 20
April 28			
	1st P. T.	7 18 46	7 18 42
	End		7 30
April 29			
	First trace of Waves		23 02 40 G.M.T.
	Long waves		23 48
	Maximum		24 02
	End		24 30

		N–S Component	E–W Component
		h m s	h m s
May 2	Long waves		19 14
	Maximum		19 17
	End		19 40
May 5	1st P. T.	2 48 20 (?)	2 48 20
	2nd P. T.	2 50 40	2 50 40
	P. P.	2 53 36	2 53 20
	Maximum	2 54	2 54
	End	3 20	3 24
May 12	1st P. T.	0 14 30 (?)	0 15
	2nd P. T.	0 21 16	0 21 16
	P. P.	0 25 24	0 25 14
	Maximum		0 29
	End	1 15	1 30
May 16	1st P. T.	4 18 34	4 18 28
	2nd P. T.	4 22 28	4 22 28
	P. P.	4 24 20	4 24 48
	Maximum	4 25 06	4 25 12
	End	5 00	5 00
May 17	1st P. T.	8 13 17	8 13 18
	2nd P. T.	8 21 48	8 21 47
	P. P.	8 35	8 35
	Maximum	8 22	8 23 40
	End	10 00	10 12
May 18	1st P. T.	16 58 18 (?) G.M.T.	16 58 22 G.M.T.
	2nd P. T.	17 04 46	17 04 55
	P. P.		
	Maximum	17 05 30	17 08 40
	End	18 00	18 00
May 18	1st P. T.	18 25 (?)	18 24 52
	2nd P. T.	18 31 27	18 31 29
	P. P.		
	Maximum	18 32 32	18 32 32
	End	19 17	19 18
May 23	1st P. T.	5 39 30 (?)	5 39 16
	2nd P. T.	5 46 12 (?)	5 46 16
	P. P.		5 50 36
	End		6 15

		N–S Component	E–W Component
		h m s	h m s
May 25	P. P.	5 43	5 43
	End	6 19	6 14
May 26	Waves		2 30
	Long waves		3 05
	End	3 40	3 40
	Waves	13 03·5	13 03·5
	"	14 27·5	14 27·5
	"	14 45·5	
May 30	1st P. T.	21 24 G.M.T.	21 23 47
	2nd P. T.	21 30	
	P. P.	21 34	
	End	22 00	22 10
June 3	1st P. T.	19 02 40	19 03 24
	2nd P. T.	19 15 13 (?)	19 21 (?)
	P. P.	19 30 00	19 37
	Maximum	20 03 30	20 03 30
	End	21 05	21 15

Earthquake destroyed Korinchi, Sumatra; distance 15,000 km.

		h m s	h m s
June 6	Traces	5 51	5 49
	Long Waves	5 55	5 59
	End	6 10	6 10
June 8	1st P. T.	5 57 52	5 58 00
	2nd P. T.	6 07 09	6 07 10
	P. P.	6 20	6 19 34
	Maximum	6 30	6 21
	End	7 40	8 00
June 9	1st P. T.	0 34 (?)	0 34
	2nd P. T.	0 48 08	0 48 07
	P. P.	1 09	1 08
	Maximum	1 12	1 12
	End	1 28	1 35
June 11	Long waves	20 40	
June 12	1st P. T.		20 40
	P. P.	21 42	21 36
	End	22 24	22 24

Terrestrial Magnetism

In continuation of the systematic magnetic survey of Canada, begun two years ago, the field of operations for the present season is along the north shore of the St. Lawrence River from the Saguenay River to the Straits of Belle Isle, a distance of about 650 miles. Stations will be occupied at intervals of about 25 miles, and observations for declination, inclination and horizontal intensity are made by Mr. C. A. French, for whom a small sailing yacht was chartered.

June 21, 1909. O. K.

Meridian Work

The Troughton & Simms Meridian Circle has now been mounted for some little time, and some observations have been made for testing purposes. During last winter the Observatory mechanician was engaged in repairs to the pivots, which had been found to be too soft. This delicate and exacting undertaking was performed by turning down the old pivots, which were of four inches diameter, to a smaller size, and forcing on rings of hardened steel which had been previously ground to almost the proper size; after this the outside surfaces were again ground and polished to the finished size. It was also found necessary, on account of the alterations to the pivots, to re-turn the bearings which carry the graduated circles. This was completed and the instrument mounted by the beginning of May. It was then necessary to true up the circles by scraping both the bearings on the axis and on the circles, so that the plane of the graduations should be strictly at right angles to the axis in any position of the circles. This, which is a slow and arduous undertaking, is still in progress, one circle having been completed. In the meantime the instrument has been used as a transit for testing purposes. It has also been found necessary to remodel the counterpoise system, which originally consisted of a lever system with a magnification of about 35, so that the counterpoises were each only 10 pounds in weight; on account of the friction involved by this high multiplication the counterpoises were found to be use-

less. The new ones, with a multiplication of 2½, are now almost completed; it will then be possible to use the instrument for regular transit work. There still remain, in addition to the work on the other circle, some alterations to the circle micrometers, besides a number of smaller details. In the meantime the electric wiring for lights, chronographic circuits and clocks is proceeding in both Transit Room and Meridian Circle Room. It is hoped that by the end of the year everything will be in readiness to begin a regular program of work, though it will be hampered for a time by the lack of azimuth marks, which there seems no prospect of having erected this year.

A printing chronograph of the type invented by the late Professor G. W. Hough, which has been ordered for some time, was recently received. The printing mechanism consists of three revolving tpye-wheels, to mark minutes, seconds and hundredths of seconds; the paper is brought into momentary contact with these by a magnet actuated by the observing circuit; the type-wheels are controlled by the observing clock. It has been found desirable to make some slight alterations in the details of the printing mechanism, which will be completed in the near future. It is hoped by means of this instrument to save much labor in scaling the chronographic records, and also to probably somewhat increase the accuracy of the registration.

R. M. S.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary of the Weather in Canada

APRIL, 1909

Temperature.—The temperature of April was below the average, except in portions of Prince Edward Island and Cape Breton where the average was somewhat exceeded. The negative departures were marked, especially in the Western Provinces where they ranged from 9 to 12 degrees. The northern portions of British Columbia, Ontario and Quebec also recorded as much as 7 and 8 degrees below the normal.

For the highest and lowest temperatures see the accompanying table.

Precipitation.—In British Columbia the precipitation was much below the average amount except in Cariboo where there was more than usual. In Alberta and Saskatchewan there was a positive amount in some districts and a negative in others. Calgary recorded one hundred per cent. above the average, whilst Battleford experienced one hundred per cent. below the average quantity. In Manitoba the excess throughout the Province ranged from 31 to about 50 per cent. Elsewhere in the Dominion the precipitation was largely above the average, except in the eastern portion of Quebec and in parts of Prince Edward Island and Cape Breton where the deficiency was rather marked. In the Province of Ontario the positive departure was very generally from 2 to 4 inches. Snow fell at intervals, the usual April snowfall in the several Provinces being as a rule much exceeded.

MAY, 1909

Temperature.—The mean temperature of May was somewhat in excess of the average in Northeastern New Brunswick, North-

Temperatures for April and May

Station	April		May	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	52	-12	72	23
British Columbia				
Agassiz	71	29	78	30
Atlin	48	- 4	62	24
Barkerville	48	8	64	20
Kamloops	70	26	88	32
New Westminster	64	30	74	34
Vancouver	61	28	71	35
Victoria	63	32	72	34
Western Provinces				
Banff	55	6	67	20
Battleford	52	4	80	22
Calgary	60	10	76	22
Carberry	54	- 1	72	23
Edmonton	56	1	79	26
Medicine Hat	64	11	80	30
Minnedosa	48	7	78	15
Moosejaw	63	- 1	82	15
Morden	62	5	83	17
Oak Bank			80	19
Portage la Prairie	58	12	79	20
Prince Albert	46	-14	80	14
Qu'Appelle	56	0	78	12
Regina	60	- 1	79	9
Swift Current	62	6	80	20
Winnipeg	58	9	82	20
Ontario				
Agincourt	63	15	63	15
Alton	64	6		
Aurora	67	11	79	29
Bancroft	61	5	77	25
Beatrice	60	4	75	29
Birnam	69	17	79	30
Bloomfield	61	18	72	33
Brantford	70	14	83	30
Bruce Mines	55	6	85	23
Chatham	76	19	86	30
Clinton	67	10	80	30
Cottam	72	16	80	22
Cockburn Island	57	8	80	24
East Toronto	62	14	81	30
Gravenhurst	62	0	76	28
Haliburton	64	0	81	27
Hamilton	70	18	85	33
Huntsville	60	0	75	28
Kenora				
Kinmount	64	- 6	79	25
Kingston	57	17	77	34
Lakefield	60	12	84	32
London	70	16	85	29
Lucknow	65	10	79	27
Meaford	64	10	73	32
Midland	60	15	80	32
North Gower	67	15	87	27
Otonabee	64	15	78	35
Ottawa	66	14	75	30
Owen Sound	65	14	80	30
Paris	69	16	83	31
Parry Sound	59	8	75	27
Peterboro'	68	10	77	28
Point Clark	71	22	76	31
Port Arthur	54	2	80	17
Port Burwell	60	16	76	32
Port Dover	71	15	78	29
Port Hope	57	16	80	23
Port Stanley	62	16	77	30
Rockliffe	56	4	74	25
Ronville	59	- 1	79	26
Sarnia	68	20		
Southampton	65	11	80	29
Stony Creek	71	15	82	34
Stratford	63	16	81	27
Toronto	61	16	82	31
Uxbridge	67	12	78	29
Wallaceburg	73	19	80	29
Welland	68	14	78	32
White River	48	20	81	15
Windsor	74	21		
Quebec				
Brome	64	15	77	28
Father Point	52	18	70	30
Montreal	66	20	74	33
Quebec	61	14	73	32
Sherbrooke	66	15	77	30
Maritime Provinces				
Charlottetown	59	21	72	30
Chatham	60	9	76	30
Fredericton	57	12	76	29
Halifax	62	21	71	31
Moncton	60	17	73	31
St. John	53	18	68	33
St. Stephen	63	16	79	30
Sussex	59	10	75	28
Sydney	67	21	72	29
Yarmouth	55	22	65	32

ern Manitoba and in parts of Northern and Western Saskatchewan, and below the average in other portions of the Dominion; the largest negative departures, from 3° to 4°, occurred in the more central counties of Ontario and in British Columbia. These conditions following a rather cold April led to vegetation being backward in nearly all parts of the Dominion.

For the highest and lowest temperatures see the accompanying table.

Precipitation.—The rainfall of the month was somewhat excessive in Quebec and in Southern and Eastern Ontario and over most of Nova Scotia; also in Alberta and Southern Saskatchewan, while in nearly all other districts there was a deficiency, which on Vancouver Island and in Ontario north of the Great Lakes was fairly pronounced. R. F. S.

MAGNETIC VALUES—AGINCOURT

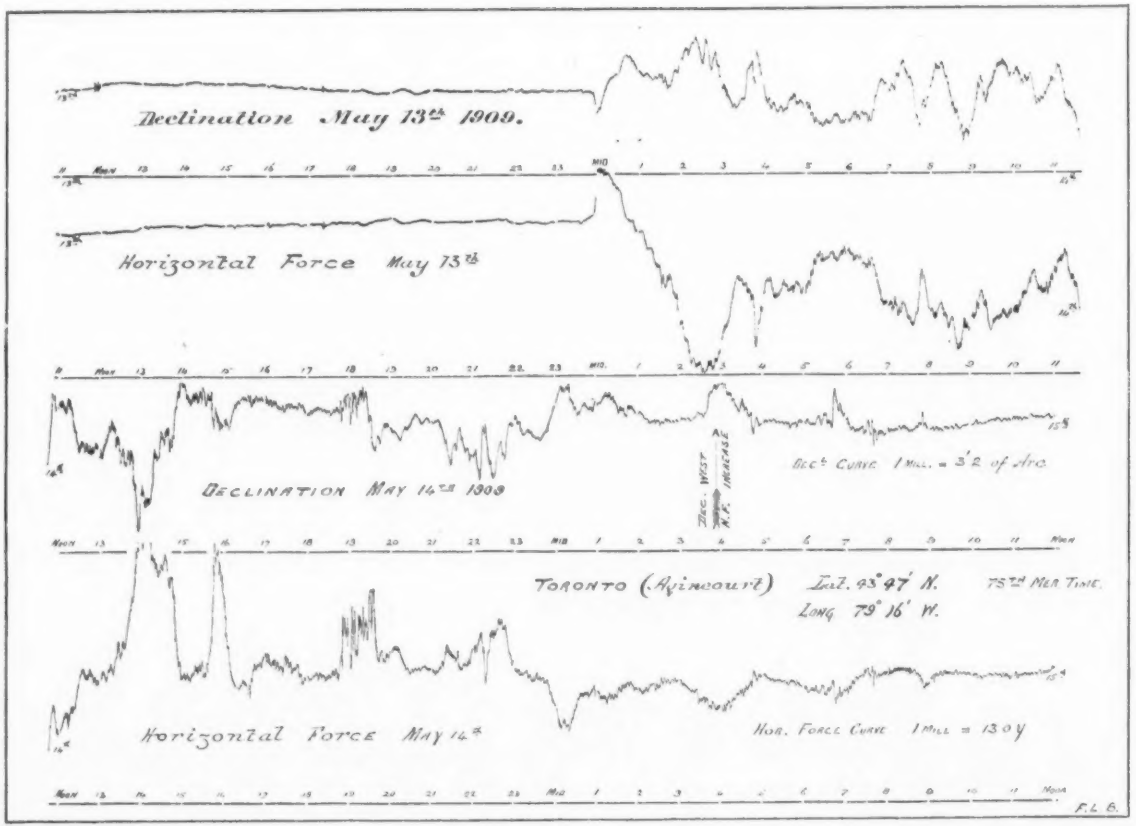
	DECLINATION	INCLINATION
April	5° 58′·5 W.	74 36·7
May	5° 59′·0 W.	74 36·5

	HORIZONTAL COMPONENT	VERTICAL COMPONENT
April	0·16329	0·59331
May	0·16326	0·59305

The magnets were quiet throughout April, except from the 24th to 26th, during which days there were small disturbances. The first part of May was also a quiet period, but towards midnight at $23^h\ 57^m$, 75th Meridian time, a violent disturbance began, with an abrupt swing of the declination magnet to the eastward and an increase in H of 125γ. On the 14th, at $2^h\ 20^m$, the declination was 38′ west of the monthly mean, and at $13^h\ 57^m$ it was 1° 15′·3 to the eastward of the mean.

A disturbance of lesser magnitude occurred during the 18th and the early morning hours of the 19th.

The chart on the opposite page shows the records at the Toronto (Agincourt) Observatory of an extensive magnetic storm on May 13–14, 1909.


Declination May 13th 1909.
Horizontal Force May 13th
Declination May 14th 1909
Dec. West
N.F. Increase
Dec. Curve 1 Mill. = 3'2 of Arc
Toronto (Rhinecourt)
Lat. 93° 97' N.
Long 79° 16' W.
75th Mer Time.
Horizontal Force May 14th
Hor. Force Curve 1 Mill = 13.0 γ
F. L. B.

Earthquake Records by Milne's Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. Time is Greenwich Civil Mean Time, 0 or 24 H = midnight.

No.	Date 1909		P.T. Commence	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
			h m	h m	h m	h m	mm.	h m	
830	Jan.	12	0 6·1			0 10·1	0·15	0 4·0	Thickening, Vancouver.
831	"	12	10 25·7			10 27·7	0·1	0 2·0	
832	"	12	12 29·7		12 34·0	12 51·7	0·3	0 22·0	Very small, well marked.
833	"	21	21 46·9			21 50·9	0·1	0 4·0	[Persia.
834	"	23	3 14·1	3 27·6	3 44·6	4 35·1	1·05	1 21·0	Persia, also felt in Sicily.
835	Feb.	9	12 11·0?						Mixed up with air currents.
836	"	16	16 53·5		16 57·8	17 10·0	0·15	0 16·5	Marked thickening. Skag-
837	"	22	9 43·4) 45·6)	9 48·9	9 52·8	11 0·0	0·6	1 16·6	[way.
838	"	26	No P.T's	17 0	17 0·2	17 39·0?	1·0	0 39·0?	Max. shortly after beginning
839	Mar.	13	0 0·0			1 2·0	0·3	1 2·0	V'y sm., w. def. Jap., Manila
840	"	13	14 47·3			16 29·0	0·3	1 41·7	Or. 1100 m. off. Arva-Kayuan
841	Apr.	10	5 52·0			6 0·0	0·1	0 8·0	Doubtful [Japan
842	"	10	6 20·5		6 47·8	7 31·8	0·4	1 11·3	Small & Prolonged. Peru.
843	"	10	19 5·8	19 17·8	19 20·8	20 6·3	3·2	1 0·5	Medium.
844	"	10	20 10·8		20 25·0	21 23·3	0·6	1 12·5	Apparently another quake
845	"	12	2 38·0			2 58·5	0·1	0 20·5	[but very much smaller.
846	"	23	18 9·7			18 33·6	0·05	0 23·9	Portuguese earthquake.
847	"	24	13 52·6			13 56·0	0·1	0 3·4	
848	"	25	1 26·0			1 32·9	0·15	0 6·0	
849	May	5	2 52·0			2 55·0	0·15	0 3·0	
850	"	12	0 21·0		0 29·9	0 57·0	0·4	0 36·0	
851	"	13	14 0·1			14 6·3	0·15	0 6·2	[Canadian, N.W. Provinces
852	"	16	4 26·5			4 30·0	0·05	0 3·5	Very slight thickening.
853	"	17	8 14·0?	8 32·0	8 32·7	10 22·0	3·9	2 8·0	Moderate. Peru, Chili.
854	"	18	16 58·8		17 7·6	17 48·0	0·7	0 49·2	
855	"	18	18 30·8			19 0·2	0·05	0 29·4	
856	"	23	5 52.4			5 58·4	0·1	0 6·0	
857	"	27	14 3·0			14 7·0	0·15	0 4·0	

Period 14·9 seconds

1 mm. 0".70

Earthquake Records by Milne's Seismograph

Victoria, B. C.

E. B. Reed, Superintendent.

P.T. = Preliminary Tremors. L.W. = Large Waves. Time is Greenwich Civil Mean Time, 0 or 24 H = midnight.

No.	Date 1909	P.T. Commence	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
		h m	h m	h m	h m	mm.	h m	
850	Jan. 11	No P.T's	23 48·8	23 48·8	24 18·8	6·0	30	Earthquake, Vancouver,
851	" 12	10 42·6			10 45·3	0·05	2·7	[Victoria & North Pacific.
852	" 12	12 43·3		12 50·8	13 00	0·15	0 16·7	Persia.
853	" 21	21 27·1		21 27·3	21 35·1	0·9	0 8·0	
854	" 23	3 14·1	3 26·6	3 48·1	5 0·1	0·8	1 45·3	Small & extended, Persia.
855	Feb. 9	12 20·4			12 33·6	0·1	0 13·2	Thickening.
856	" 16	16 41·8		16 44·2	16 58·8	4·0	0 17·0	Medium. Skagway & Atlin,
857	" 22	9 36·0		9 47·5	11 4·0	1·0	0 28·0	Small. [B. C.
858	" 26	16 55·5		17 17·5	17 31·5	0·5	0 36·0	
859	Mar. 12	23 38·4		24 15·4	25 5·0	0·25	1 26·6	
860	" 13	14 39·0	14 58·5	15 0·5	16 4·5	0·5	1 25·5	Manilla.
861	" 19	22 12·3			22 16·3	0·05	0 4·0	Irregular thickening.
862	" 30	10 52·6			10 56·9	0·05	0 4·3	
863	Apr. 10	5 49·0		5 49·2	6 59·5	0·3	1 10·0	Very small, prolonged, Peru.
864	" 10	19 2·0 6 6	19 14·4	19 15·8	21 8·4	3·2	2 6·4	Medium.
865	" 12	2 34·8			2 40·3	0·05	0 5·5	
866	" 23	18 34·0?			18 37·5	0·05	0 3·0	Near Lisbon.
867	" 24	13 35·5		13 36·5	13 43·5	1·0	0 8·0	
868	" 25	1 9·3		1 11·5	1 18·5	2·0	0 9·2	
869	May 5	2 0·0?			2 35·0	0·15	0 35·0	Marked thickening.
870	" 9	21 34 6			21 39·6	0 1	0 5·0	
871	" 12	0 24·0		0 44·8	0 56·5	0·9	0 32·5	
872	" 13	14 13·4			14 25·4	0·1	0 12·0	
873	" 16	4 19·3			4 23·3	0·15	0 4·0	Prairie Provinces.
874	" 17	8 14·8	8 25·4	8 28·0	9 58·2	2·0	1 43 4	Medium & extended, Peru.
875	" 18	1 24·2			1 33·2	0·3	0 9·0	
876	" 18	11 44·9			11 48·1	0·15	0 4·8	
877	" 18	No P.T's	16 46·7	16 49·0	17 6·6	6·1	0 19·9	Began with a max. immedi-
878	" 18	17 42·6			17 47·1	0·05	0 4·5	[ately after commencement.
879	" 18	No P.T's	18 13·1	18 16·2	18 29·1	2·5	0 16·0	Very much like No. 877.
880	" 20	10 36·0			10 43·0	0·2	0 7·0	

Vibration of boom 15 seconds.

1 mm. = 0″·76.

J. Y.

ASTRONOMICAL NOTES

THE Bruce gold medal of the Astronomical Society of the Pacific, for distinguished services rendered to astronomy, was this year awarded to Dr. George William Hill, for his researches on, and contributions to the lunar theory.

IN the current number of the *Journal of the British Astronomical Association*, W. F. Denning thus speaks an encouraging word for amateurs: "Professionals and amateurs are in a certain degree mutually dependent on each other, for the latter obtain some of the observations and make a portion of the discoveries which are utilized by their better-trained and mathematical confrères. The great number of amateurs and the extremely diversified character of their work, methods, and appliances enable them, either by accident or design, to frequently pick up new objects or to recognise occasional phenomena or novel features which might elude detection but for their vigilance." (No. 8, p. 353).

Nature for April 8, contains an item to the effect that "Professor Wolf, of Heidelberg, has obtained a spectrum of the ring nebula in Lyra, using the ring itself as a slit. The dimensions of the rings obtained correspond to the four gases of which the nebula is composed. The innermost, *A*, is composed of an unknown gas, the next, *B*, is hydrogen, *C* is helium, and the outermost, *D*, is also unknown."

MR. E. A. FATH, in the *Lick Observatory Bulletin* (No. 149), describes investigations of spiral nebulæ made with the Crossley reflector and a specially designed spectrograph. "No spiral nebula investigated has a truly continuous spectrum, though this is the fundamental feature of all their spectra, which range from those having principally bright lines to those which, like the Andromeda nebula, have only absorption lines of the solar type. The spectra are best explained by supposing the spiral nebulæ to be unresolved star clusters with gaseous envelopes."

J. R. C.

PREDICTIONS FOR MAY AND JUNE

PREPARED BY E. M. STEWART

Constellations on the Meridian in July

Scorpio, the eighth sign and ninth constellation of the zodiac, is of very irregular shape. It is only by virtue of two long projections to the north that it is ranked as a zodiac constellation at all, as nearly all the stars belonging to it are some distance south of the ecliptic. As it is, the Sun spends only nine days out of twenty-five in Scorpio, the other sixteen being occupied in passing through Ophiucus, which, however, is not counted among the zodiac constellations. Its principal star is Antares, of the first magnitude, whose color is a decided red. When viewed through a telescope its color appears interspersed with intermittent flashes of green, which is explained by the presence of a close green companion, which under ordinary atmospheric conditions can not be separated from the rays of Antares itself. At its greatest altitude it is only about 20° above the southern horizon; it passes the meridian at 9 P.M., local time, on July 13.

Ophiucus (The Serpent-Bearer) is situated almost directly above Scorpio; though occupying a considerable space in the sky, it is not a very conspicuous constellation. Its highest part is marked by the star α, of the second magnitude, which is about half-way between Antares and Vega.

Serpens (The Serpent) is a divided constellation, the principal part being to the north-west of Ophiucus; there is, however, one corner to the south-east of the latter. When it received its name in antiquity it was probably considered to consist of a trail

of stars stretching right across, or perhaps in imagination coiled around, Ophiucus, whence arose the name of the latter. It contains no stars brighter than the third magnitude.

Hercules, a large constellation, is bounded on the north and south by Draco and Ophiucus, and extends east and west nearly from Arcturus to Vega. It has no very conspicuous stars, but contains many good telescopic objects. It is interesting as marking that part of the heavens towards which the solar system is at present travelling.

Constellations on the Meridian in August

Lyra is a small constellation, but contains several fairly bright stars. The principal one of these is Vega, which ranks second or third in the heavens in brightness. It is of a brilliant bluish-white color and cannot fail to be easily identified. It crosses the meridian at 9 P.M. on August 15, when it is only a few degrees south of the zenith. There is no time of year when it is not visible at some hour of the night. Twelve thousand years hence it will be the pole star, though not so near the Pole as Polaris is now. The other most interesting objects in the constellation are the doubles β and ε, the former of which is also variable, and the annular nebula near β; these are mentioned elsewhere in these Predictions.

Sagittarius (The Archer), the ninth sign and tenth constellation of the zodiac, passes low in the south at the same time that Vega is on the meridian. It contains a group of seven fairly bright stars, about 30° to the east of Antares and at about the same altitude. It is occupied by the Sun from the middle of December to the middle of January, and contains the most southern point of the ecliptic.

Draco (The Dragon) is a very large and winding constellation in the neighborhood of the Pole, and almost completely surrounds Ursa Minor, of which Polaris is the principal object. It includes several second magnitude stars and others between Vega and the Pole, extending also westward in a wide curve around Ursa Minor.

THE CONSTELLATIONS ON AUGUST 1, AT 9 P.M.

SOME INTERESTING DOUBLES VISIBLE IN SMALL TELESCOPES

—*Draconis*. R. A. $15^h\ 58{\cdot}6^m$; Dec. 59° 12′; magnitudes 7·5, 9·2, 7·7; distances 1″·6, 43″·5; all three stars probably form one system.

η Draconis. R. A. $16^h\ 22{\cdot}8^m$; Dec. 61° 43′; magnitudes 2·1, 8·1; distance 4″·7; 11′ north is another close pair forming a binary system; magnitudes 5·7, 6·9; distance 0″·9.

α Herculis. R. A. $17^h\ 10{\cdot}5^m$; Dec. 14° 30′; magnitudes 3, 6·1; distance 4″·6; colors very yellow and intense blue; it has been called one of the finest objects in the heavens; the larger component is irregularly variable.

ν Draconis. R. A. $17^h\ 30{\cdot}4^m$; Dec. 55° 14′; magnitudes 4 6, 4·6; distance 61·7; common proper motion; a beautiful object.

ζ¹ Draconis. R. A. $17^h\ 43{\cdot}6^m$; Dec. 72° 12′; magnitudes 4, 5·2; distance 30″·9.

95 *Herculis*. R. A. $17^h\ 57{\cdot}5^m$; Dec. 21° 36′; magnitudes 4·9, 4·9; distance 6″·1; colors green, red.

—*Draconis*. R. A. $18^h\ 31{\cdot}8^m$; Dec. 52° 16′; magnitudes 5·9, 8·1; distance 25″·7; colors yellow, blue.

46 *Draconis*. R. A. $18^h\ 40{\cdot}8^m$; Dec. 55° 26′; magnitudes 5′ 9; full yellow, clear blue; fine contrast.

ε Lyræ. R. A. $18^h\ 41{\cdot}4^m$; Dec. 39° 30′; composed of two components, ε^1 and ε^2, about 207″ apart, each of which is a binary. ε^1, magnitudes 4·6, 6·3; distance 3″·0; period of rotation perhaps 2000 years. ε^2, magnitudes 4·9, 5·2; distance 2″·6; period perhaps 1000 years. Between ε^1 and ε^2 are three minute stars, one of the tenth magnitude, the others of the thirteenth. The system is about a degree to the north-east of Vega.

—*Aquilæ*. R. A. $18^h\ 46{\cdot}5^m$; Dec. 10° 52′; magnitudes 5·8, 7; distance 3″·5; fine contrast in colors.

β Lyræ. R. A. $18^h\ 46{\cdot}7^m$; Dec. 33° 15′; magnitudes 3, 6·7; distance 45″·8. The brighter component varies in magnitude from 3·4 to 4·5 in $12^d\ 21^h\ 46^m\ 58{\cdot}3^s$, two maxima and two unequal minima occurring within that time. A very interesting object.

Variable Stars

Name	R. A.	Dec.	Mag.	Period
	h m	° ′		
S Draconis	16 41·0	55 6	7·3 to 9·2	Unknown
U Ophiuchi	17 11·9	1 18	6 to 6·7	20h 7m 42·56s
X Sagittarii	17 41·9	−27 48	4 to 6	7·011 85 days
β Lyræ	18 46·7	33 15	3·4 to 4·5	12d 21h 46m 58·3s
U Aquilæ	19 24·5	− 7 14	6·4 to 7·1	7·026 45 days
η Aquilæ	19 47·8	0 46	3·5 to 4·7	7d 4h 14m

Radiant Points of Meteor Showers

Date	R. A.	Dec.	
	h m		
July 23–25	3 12	43°	Near *β Persei* (Algol).
July 28	22 44	−13	
August 9–11	3 0	57	The "Perseids." Near *η Persei*
August 21–25	12 27	60	Near *o Draconis*

Meridian Passage of the Principal Planets during July and August

LOCAL MEAN TIME

	For July 15		For August 15
Mercury	10.43 A.M.	{ Taurus, Gemini, Cancer, Leo, Virgo }	12.50 P.M.
Venus	1.34 P.M.	Cancer, Leo, Virgo	1.56 P.M.
Mars	4.27 A.M.	Pisces	2.59 P.M.
Jupiter	3.24 P.M.	Leo	1.43 P.M.
Saturn	5.58 A.M.	Pisces	3.57 A.M.
Uranus	11.49 P.M.	Sagittarius	9.42 P.M.
Neptune	11.42 A.M.	Gemini	9.44 A.M.

Venus and Jupiter

Both these planets are now visible in the western sky in the early evening, Venus near the horizon and Jupiter higher up. Jupiter, which has been sinking toward the western horizon, will continue to do so during July and August, after which it will disappear in the Sun's rays. Meanwhile Venus continues to rise steadily higher, reaching a distance of about 30° from the Sun by the end of August. On August 12, at 2 A.M. the two planets, will be in conjunction, being separated by only about one-third

of the Moon's apparent diameter, Venus being slightly higher. The Moon will be in conjunction with Venus on the morning of July 19, and with Jupiter on the morning of July 21 ; again with Jupiter on the evening of August 17, and with Venus on the morning of August 18.

Mercury

Mercury is at its greatest elongation west on July 7, continuing as a morning star until August 4 ; by the middle of August it will be again coming into visibility as an evening star. It is in conjunction with Jupiter on the morning of August 25, being at that time slightly more than the diameter of the Moon to the south of the latter, while Venus is about 12° to the east.

Mars

Mars will be rapidly approaching the earth during the months of July and August, and accordingly becomes an increasingly conspicuous object. It will not, however, be at its brightest until September, when it is in opposition. It is now visible in the eastern sky during the latter half of the night, rising at about 10 P.M. at the beginning of August. It is at present moving to the eastward among the stars, but begins to retrograde on August 23. It is in conjunction with the Moon on the morning of July 7 and the morning of August 5.

Saturn

Saturn remains practically stationary among the stars, its whole motion during these two months being less than a degree ; it begins to retrograde on August 5. It continues to be approached by Mars until August 25, when the two planets are separated by only 16°, Saturn being to the eastward. It is in conjunction with the Moon on July 10 and August 6.

Clusters and Nebulæ

M 13. Globular cluster. R. A. $16^h\ 38{\cdot}4^m$; Dec. 36° 36′ ; lying one-third of distance from η to ζ *Herculis* ; just visible to the naked eye ; the finest cluster of its class ; Herschel estimated number of stars at 14,000.

ν 5 N. Small but bright planetary nebula of 8″ diameter. R. A. $16^h\ 40{\cdot}7^m$; Dec. 23° 58′; of an intense blue color; surrounded by a slight glow.

M 92. Cluster. R. A. $17^h\ 14{\cdot}4^m$; Dec. 43° 14′; the stars are brighter and more compressed than in *M* 13; hence it is less resolvable; it possibly shows traces of spiral structure.

M 8. R. A. $17^h\ 58{\cdot}2^m$; Dec. −24° 22′; in a large field there is visible a bright, coarse triple star, followed by a resolvable luminous mass, including two stars, or starry centres, and then by a loose bright cluster of several stars; a very fine combination.

H IV. 37. Planetary nebula. R. A. $17^h\ 58{\cdot}6^m$; Dec. 66° 38′. Shows as a luminous disc of about 20″ diameter. This was the first nebula to be proved gaseous; the analysis of its spectrum was made by Huggins, August 29, 1864.

M 57. The Ring Nebula in Lyra. R. A. $18^h\ 50{\cdot}2^m$; Dec. 52° 55′. The only ring nebula accessible by small telescopes. It is easily found, being one-third of the distance from β towards γ *Lyræ*. It is somewhat oval, and bears magnifying well; a beautiful and interesting object.

Halley's Comet

Halley's Comet, whose last return occurred in 1835, is now rapidly approaching, being probably some four or five hundreds of millions of miles distant. It is at present hidden by the rays of the Sun, which is nearly in line between it and the earth. Soon, however, the search for it will begin, and it will in all likelihood be discovered by the aid of photography towards the end of July. During August it will be in the prolongation of the line from the belt of Orion through Betelgeuse, the bright star in his shoulder, being about the same distance above Betelgeuse that the belt is below; it is then some 50° westward from the Sun, and should be fairly accessible to photography. According to the ephemeris of Messrs. Cowell and Crommelin it should pass perihelion about April 8, 1910, not, however, reaching its greatest brightness till about May 10, when its distance from the earth will be only seven or eight millions of miles.

At Greenwich Mean Noon

Date 1909	Day of Year	The Sun's Right Ascension	The Sun's Declination	Equation of Time Sub't from Mean Time	Sidereal Time
		h m s	° ′ ″	m s	h m s
Thur. 1	182	6 39 4·34	N. 23 8 51·8	3 28·95	6 35 35·39
Sun. 4	185	6 51 27·65	22 55 27·8	4 2·58	6 47 25·07
Wed. 7	188	7 3 48·24	22 38 28·4	4 33·50	6 59 14·74
Sat. 10	191	7 16 5·69	22 17 57·3	5 1·28	7 11 4·41
Tues. 13	194	7 28 19·57	21 53 58·6	5 25·49	7 22 54·08
Fri. 16	197	7 40 29·42	21 26 37·2	5 45·66	7 34 43·76
Mon. 19	200	7 52 34·71	20 55 58·3	6 1·28	7 46 33·43
Thur. 22	203	8 4 35·08	20 22 8·5	6 11·99	7 58 23·10
Sun. 25	206	8 16 30·20	19 45 14·4	6 17·44	8 10 12·77
Wed. 28	209	8 28 19·88	19 5 23·1	6 17·44	8 22 2·44
Sat. 31	212	8 40 4·02	18 22 42·2	6 11·91	8 33 52·11

75th Meridian Time, Hours numbering from Midnight

		Planetary Phenomena	Minima of Algol h m	Configuration of Jupiter's Satellites at 2h 30m
Thur.	1			23○14
Fri.	2	11h ☿ Greatest heliocentric latitude S.		1○234
☽ Sat.	3	7h 17·3m Full Moon; 21h 31m ☌ ♅ ☾, ♅ 2° 22′ N;	5 56	○2134
Sun.	4	[22h, ♁ in Aphelion.		21○34
Mon.	5			32○14
Tues.	6		2 45	31○24
Wed.	7	15·0h ☾ in Perigee.		2132○4
Thur.	8	oh ☿ Greatest elong. W., 21° 12′; 10h 45m ☌ ♂ ☾.	23 34	234○1
Fri.	9	13h ☌ ♆ ☉. [♂ 1° 21′ N.		41○23
☾ Sat.	10	1h 58·1m Last Quarter; 9h 46m ☌ ♄ ☾, ♄ 1° 54′ N.		4○123
Sun.	11	22h ☍ ♅ ☉.	20 23	421○3
Mon.	12			2142○1
Tues.	13			431○2
Wed.	14		17 12	2143○1
Thur.	15	15h 36m ☌ ☿ ☾, ☿ 2° 48′ S.; 21h □ ♄ ☉.		423○●
Fri.	16	15h 42m ☌ ♆ ☾, ♆ 3° 21′ S.; 17h ☿ Greatest Hel.		14○23
♋ Sat.	17	5h 44·6m New Moon. [Lat. N.	14 01	○1243
Sun.	18			21○34
Mon.	19	oh 50m ☌ ♀ ☾, ♀ 3° 5′ S.		2○314
Tues.	20	oh ♂ Greatest Heliocentric Latitude S.	10 50	31○24
Wed.	21	oh 39m ☌ ♃ ☾, ♃ 4° 22′ S.; 11h ☿ in ♌.		3○214
Thur.	22			321○4
Fri.	23	13h ☾ in Apogee; 12h ☌ ☿ ♆, ☿ 1° 6′ N.	7 39	2143○●●
Sat.	24			○1423
☽ Sun.	25	6h 45·3m First Quarter.		214○3
Mon.	26	2h ☿ in Perihelion.	4 28	42○31
Tues.	27			431○2
Wed.	28			43○21
Thur.	29		1 17	4321○
Fri.	30			2143○●●
Sat.	31	5h 3m ☌ ♅ ☾, ♅ 2° 18′ N.	22 06	4○23●

Key to Symbols.—☌ Conjunction; ☍ Opposition; □ Quadrature; ☊ Ascending Node; ☋ Descending Node; ☉ Sun; ☿ Mercury; ♀ Venus; ♁ Earth; ♂ Mars; ♃ Jupiter; ♄ Saturn; ♅ Uranus; ♆ Neptune.

At Greenwich Mean Noon

Date 1909	Day of Year	The Sun's Right Ascension	The Sun's Declination	Equation of Time Sub't from Mean Time	Sidereal Time
		h m s	° ′ ″	m s	h m s
Sun. 1	213	8 43 57·51	N. 18 7 52·2	6 8·84	8 37 48·66
Wed. 4	216	8 55 34·36	17 21 36·6	5 56·03	8 49 38·33
Sat. 7	219	9 7 5·92	16 32 48·8	5 37·92	9 1 28·00
Tues. 10	222	9 18 32·35	15 41 36·2	5 14·88	9 13 17·66
Fri. 13	225	9 29 53·77	14 48 7·0	4 46·45	9 25 7·33
Mon. 16	228	9 41 10·30	13 52 29·5	4 13·31	9 36 56·99
Thur. 19	231	9 52 22·08	12 54 52·7	3 35·43	9 49 46·66
Sun. 22	234	10 3 29·35	11 55 25·4	2 53·02	10 0 36·32
Wed. 25	237	10 14 32·38	10 54 16·6	2 6·39	10 12 25·99
Sat. 28	240	10 25 31·55	9 51 35·3	1 15·90	10 24 15·65
Tues. 31	243	10 36 27·30	8 47 30·0	0 21·99	10 36 5·31

75th Meridian Time, Hours numbering from Midnight

Planetary Phenomena

			Minima of Algol	Configuration of Jupiter's Satellites at 20h
			h m	
☿ Sun.	1	16h 14·0m Full Moon.		412○3
Mon.	2			2○13●
Tues.	3	23·0h ☾ in Perigee.	18 55	13○24
Wed.	4	7h ☌ ☿ ☉ Superior.		3○214
Thur.	5	9h ☿ Greatest Hel. Lat. N.; 11h 14m ☌ ☾, ☌ 0° 13′ S.		321○4
Fr.	6	5h ♄ Stationary; 16h 45m ☌ ♄ ☾, ♄ 1° 33′ N.	15 44	23○14
Sat.	7			○234●
☾ Sun.	8	7h 9·9m Last Quarter.		12○34
Mon.	9		12 33	2○134
Tues.	10			13○42
Wed.	11			34○12
Thur.	12	2h ☌ ☿ ♃, ☿ 0° 12′ N.; 23h 56m ☌ ♆ ☾, ♆ 3° 29′ S.	9 21	4321○
Fri.	13	14h ☌ in Perihelion.		432○1
Sat.	14			41○32
☽ Sun.	15	18h 54·7m New Moon.	6 10	♃♃4○3
Mon.	16	17h 56m ☌ ☿ ☾, 3° 53′ S.		42○13
Tues.	17	18h 36m ☌ ♃ ☾, ♃ 4° 17′ S.		
Wed.	18	7h 12m ☌ ☿ ☾, ☿ 4° 14′ S.	2 59	
Thur.	19	17·7h ☾ in Apogee.		
Fri.	20		23 48	
Sat.	21			
Sun.	22			
☽ Mon.	23	10h ☌ Stationary; 22h 55·3m First Quarter.	20 37	
Tues.	24			
Wed.	25	7h ☌ ☿ ♃, ☿ 0° 40′ S.		
Thur.	26		17 26	
Fri.	27	13h 38m ☌ ♇ ☾, ♇ 2° 22′ N.		
Sat.	28	20h ☿ in ♌.		
Sun.	29		14 15	
Mon.	30			
☿ Tues.	31	oh 7·8m Full Moon.		

Invisible on account of proximity to Sun.

For Jupiter's Satellites, the circle ○ represents the disc of the planet; ♃ signifies that the satellite is on the disc; ● signifies that the satellite is behind the disc or in the shadow. Configurations are for an inverting telescope.

ECLIPSES AND TRANSITS OF THE SATELLITES OF JUPITER

E = eclipse, O = occultation, T = transit, S = shadow, D = disappearance, R = re-appearance, I = ingress, e = egress.

Eastern Standard Time; hours numbering from noon.

JULY

d	h	m			d	h	m			d	h	m		
7	8	5	I.	TI	**8**	8	37	I.	ER	**23**	8	38	III.	ER
	9	8	I.	SI		8	51	IV.	SI		8	52	I.	Te
	9	36	II.	Se	**14**	9	24	II.	SI	**30**	8	33	I.	TI

AUGUST

d	h	m			d	h	m			d	h	m		
7	7	49	I.	OD	**8**	8	5	II.	Te	**15**	7	37	I.	SI
8	8	00	I.	Se										

OCCULTATIONS OF STARS BY THE MOON*

HOURS NUMBERING FROM NOON

Date		Star	Mag.	Time		Position Angle	
				Immersion	Emersion	Immersion	Emersion
				h m	h m	°	°
July	5	143 β *Capricorni*	6·1	14 18·4	15 31·9	78	234
"	10	64 *Ceti*	5·8	14 20·9	13 21·4	50	252
"	27	84 β *Scorpii*	6·3	9 58 5	11 15·0	103	284
August	4	33 *Piscium*	4·7	10 43·0	11 12·5	36	266
"	4	24 β *Ceti*	6·0	13 18·2	14 24·7	79	217
"	5	26 *Ceti*	6·0	13 54·7	14 43·2	9	282
"	29	143 β *Capricorni*	6·1	8 21·4	9 39·4	76	247
"	29	154 β *Capricorni*	6·1	13 16·9	14 20·9	48	257
"	30	69 *Aquarii*	5·6	11 22·3	12 27·8	84	218
"	30	τ *Aquarii*	4·4	12 41·0	13 50·0	46	251

* The data for these occultations have been kindly supplied by Mr. Mother-well. The times and position angles have been calculated for the Dominion Observatory, and will be somewhat different for other points.